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RECENT DEVELOPMENTS IN OCCUPATIONAL HEALTH IN THE UNITED STATES

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Abstract—Occupational health in the United States in recent years has been influenced by three national trends: (1) accelerated medical research supported largely by federal grants, (2) the inter-action between in-plant and community problems, and (3) the vigorous growth of in-plant health programs.

Demonstrable progress has been made in the development of chemical, physical, toxicologic, and epidemiologic methods and techniques for the study and control of occupational diseases.

Recent studies have included attempts (1) to further elucidate the cause and effective control of dust diseases, (2) to more clearly define the effects and control of radiation, (3) to determine the causes and prevention of occupational dermatoses, (4) to evaluate industrial noise and devise methods for noise reduction, and (5) to determine the toxic effects of exposure to a growing number of chemicals finding application in industry.

Legal and other factors, together with certain medical developments, have contributed to the growth of occupational health services.

INTRODUCTION

IN A large federal commonwealth such as the United States, with marked differences among the fifty states in population density, types of industry, and adequacy of occupational health services, it is sometimes difficult to define what represents truly national trends. Nevertheless, a few national trends are discernible.

The first of these is the tremendous upsurge in medical research in this country supported in large degree by grant programs of the Federal Government. The National Institutes of Health of the United States Public Health Service started its research grants program in 1946 with a total appropriation of \$780,158. During 1960 these grants ran into \$198,719,397 supporting 11,572 research projects in 973 institutions in this country and in 145 institutions abroad. The National Science Foundation and the Department of Defense in 1960 likewise supported medical research in non-governmental institutions in the estimated amounts of \$24,413,000 and \$25,523,000 respectively. Most of these funds are made available on a disease category basis, and although there has been support of basic research and research in non-categorical fields, it is apparent that research in occupational diseases and industrial hygiene has received less than proportionate attention. For the next fiscal year, it is estimated that the amount of research grants supporting research in occupational diseases will approximate \$1.5 billion.

The second major trend which has concerned both industrial groups and governmental agencies has been the interaction between in-plant and community problems. In many parts of the country, there is growing concern about the economic and

health effects of air pollution and water pollution. The industrial hygienist can no longer consider his job done simply by removing noxious agents from the in-plant environment. Rather, community effects must constantly be kept in mind in the design and operation of facilities for the removal of in-plant wastes. The obverse of this community-plant relationship is illustrated in the increasing concern of in-plant safety departments with off-the-job accidents, particularly traffic accidents. A number of industries have inaugurated vigorous educational programs in their plants to reduce traffic accidents and to cut down injury by the use of seat belts.

The third national trend has been that of a vigorous growth of in-plant health programs in the years since 1946. To a considerable degree, this growth has been confined to larger plants that can, of themselves, support adequate in-plant medical facilities. This growth has been responsible for a substantial increase in the number of occupational health personnel. Between 1934 and 1958, the number of physicians in the United States specializing in industrial medicine more than doubled from 1100 to over 2300. The membership of the American Industrial Hygiene Association, composed largely of engineers and other professional personnel responsible for the control of occupational hazards in industry, increased from 350 in 1945 to 1200 in 1960. The number of registered nurses employed full time in industry increased from 9565 in 1948 to over 14,000 in 1960.

METHODOLOGY

Chemical and physical methods

Increasing concern over prolonged exposures to low levels of contaminants as found in community air pollution problems and in closed environments, such as nuclear submarines, has accelerated the search for more sensitive measures of contaminant in the atmosphere and in biologic materials. Two extremely useful techniques for the separation of desired inorganic and organic components of samples are based on the use of ion exchange resins and gas chromatography. The physical and chemical properties of synthetic organic ion exchange resins have been studied extensively. Such resins frequently provide a simple, rapid, inexpensive separation procedure which can be rapidly applied to a large number of samples. These advantages are demonstrated in the recently developed ion exchange method for the separation of fluoride from unashed urine, eliminating tedious ashing of urine samples and steam distillation. This results in a simple method which may readily be used in the most modest analytical laboratory.

Ion exchange methods are proving effective in separating trace quantities of metallic elements from biologic materials. This has proved a valuable adjunct in the preparation of samples for spectrographic analysis.

A cationic exchange method has been developed to simplify the separation of thorium from interfering substances in urine such as iron, uranium, calcium, barium, and other ions which interfere with the otherwise nonspecific thorin, morin, and Chrome Azurol S methods. Recovery determinations over the working range of the method (which includes an oxalate, an ion exchange, and a hydroxide separation to remove all undesired constituents) are reported to average 94.2 per cent (± 15.6), 95.9 per cent (± 12.2), and 98.6 per cent (± 10.4) for the morin, Chrome Azurol S, and thorin spectrophotometric procedures, respectively.

Anionic resins may be used to remove lead completely from reagents and biologic ash. The last spectroscopic traces of lead may be removed from such materials by a single pass of a 1N HCl solution of the ash or reagent through the resin bed. This results in a sample basis whose content of lead is zero and which may be used as a basis for analytical methods. Similarly, ion exchange methods have been used to effect the isolation of uranium from urine after the wet ashing of one-liter samples. This procedure has been applied in the evaluation of urinary levels of uranium in non-exposed subjects.

Gas or vapor phase chromatography, absorption-elution, gas-liquid partition, or absorption-displacement, has been employed in effecting difficult analytical separations in the industrial hygiene laboratory. While the thermal conductivity detectors used two or three years ago were not always capable of providing required sensitivity, most of these difficulties have now been overcome. MANSUR *et al.* (1959) circumvented the difficulty by employing a conventional concentration method. They collected organic vapor samples in a midjet impinger using methanol as the sampling medium. Through this approach, the investigators were able to use a chromatographic procedure for the analysis of organic vapors at threshold limit concentrations. TALVITIE (1958) combined gas-liquid partition and absorption-displacement to effect the desired sensitivity for analysis of organic vapor samples. Since these investigations, the sensitivity of detectors has been significantly improved. The commercial development of a new hydrogen flame detector and the resulting extension of the sensitivity into parts per billion range should produce a significant increase in the applications of gas chromatography in the field of industrial hygiene.

The potential analytical application of neutron activation techniques has created considerable interest among industrial hygiene chemists. SPENCER (1959) has reported preliminary experiments designed to determine potential applications and limitations of neutron activation in solving problems in industrial hygiene and toxicology.

Because of the significance of ozone in certain community air pollution problems, as well as in certain welding operations, attempts have been made to improve analytical techniques for this substance. The iodometric methods were investigated by BYERS and SALTZMAN (1958).

SALTZMAN and GILBERT (1959) employed a completely different method in an attempt to devise a specific method for ozone. Their procedure is based on the gas phase reaction of ozone with nitric oxide to produce an equivalent amount of nitrogen dioxide. The latter is then determined by SALTZMAN's method (1954). The authors report highly accurate determinations of ozone in the 0 to 20 p.p.m. range in the presence of 10- to 100-fold ratios of hydrogen sulfide and sulfur dioxide to ozone. The system has also been made portable for use in the field.

CAMPBELL and his co-workers (1959) have developed a relatively specific method for thallium in urine and air samples. Recoveries from urine samples averaged 96 ± 6 per cent.

SILL and WILLIS (1959) have used radioisotope tracers to evaluate the morin method for the determination of trace amounts of beryllium. The limit of detection appears to be $0.0004 \mu\text{g}$, using a photomultiplier attachment to the spectrophotometer equipped with a fluorescence accessory.

EVANS *et al.* (1958) report an improved procedure for the determination of

methemoglobin which has provided a means of detecting very early the development of methemoglobinemia in workers exposed to aromatic nitro- and amino compounds (1959).

The development of high energy fuels for rocket propulsion has accelerated interest in analytical methods for boron and boron hydrides. Analytical methods for these substances have been studied in some detail by HILL and his associates.

TROLL and NELSON (1958) have developed a method for the identification and quantitative determination of the urinary metabolites of aromatic amines, based on the formation of a derivative with naphthoquinone sulfonate. The reaction is believed to be generally applicable to aromatic compounds with unsubstituted amino groups.

Other analytical developments of interest include the studies of MARGERUM and SANTACANA (1960) on the evaluation of seven methods for the determination of zinc in the 1 to 100 μg range; that of KIMURA and MILLER (1960) on the separation and analysis of methyl- or ethylmercury compounds and inorganic metallic mercury vapor in air in the 100–1000 μg range; and that of MAY (1959) providing for the microdetermination of quinquivalent, trivalent, and organic phosphorus in atmospheric samples and in aqueous solutions.

A very useful compendium of approved methods was issued in 1958 by the Committee on Recommended Analytical Methods of the American Conference of Governmental Industrial Hygienists. These methods have been recommended by the committee after meeting certain performance criteria during critical testing by a referee-collaborator system. In general, the methods are very specific, have been edited carefully, and do not require elaborate equipment.

In the field of physical methods, attempts are continuing to develop mechanical means which would permit more accurate and less tedious accounting and sizing of dust particles. The use of a recording, photometric, particle-size analyzer has been reported by TALVITIE and PAULUS (1958, 1956). The mechanism of the instrument permits complete analysis within one hour instead of greater time required for complete settling. ROSS has used a gamma-ray absorption method to conduct particle size analysis of uranium oxide.

Similar counting methods for the detection of aerosol are under study through the use of a portable, lightweight, battery-operated aerosol photometer developed by the Southern Research Institute in Birmingham, Alabama. This device, based on the principle of light scattering, will count aerosols in the range of concentrations of about 10,000 to 100,000,000 particles per cubic foot of air at selected particle sizes from 0.3 to 2.0 μ . Particle size analysis of the aerosol under test is possible by manually adjusting the discriminator selector and noting the count at each selected size. The particle size distribution curves prepared from data using this aerosol photometer and the membrane filter method are in good agreement at the median size and check quite closely for about 70 per cent of the particles, i.e. from about 15 per cent to 85 per cent (1960).

A new heat recording instrument known as the Envirec was developed by the Public Health Service (1959). It records successively air temperature, wet bulb temperature, air velocity, and globe (black ball) temperature.

Of considerable recent interest are the so-called "squeeze-bulb" colorimetric gas and vapor detecting devices. Many such new devices, covering about 40 different

gases and vapors, were introduced into America by manufacturers from Japan, Germany, and the United States. Considerable interest in these devices has resulted in tests to evaluate their accuracy, sensitivity, and usefulness. The results to date suggest that the accuracy of these methods leaves much to be desired.

Toxicologic methods

The conventional methods of toxicologic testing cannot begin to meet the need generated by the rapid introduction of new chemicals into industry and commerce. Recent changes in the food and drug laws of the United States have served to accentuate this problem and have tended to divert some of the industrial toxicologic resources from industrial hygiene to the testing of materials to be used as food additives. There is an utopian wish for a series of very simplified toxicologic tests which would enable one to predict the effects on man of prolonged low-level exposures to chemicals and mixtures of chemicals. While such a solution seems far removed, certain trends in toxicologic testing are discernible.

In vitro methods have been widely used in chemotherapeutic studies and have had limited application in the field of toxicology. Where the methods of action are clearly known, the *in vitro* techniques frequently provide a method for subtle differentiations among various compounds in the same class or series of compounds. Attempts to use tissue culture in the evaluation of air pollutant agents have been disappointing. Recent studies in the Public Health Service suggest that the use of monomolecular films of protein may provide a suitable test agent for evaluation of oxidizing and reducing substances in the atmosphere.

The study of enzyme system effects in the whole animal and the study of isolated enzyme systems provide a somewhat more sophisticated method of measuring biologic effects and possibly a much more sensitive indicator of change than is provided by measures in current use. Promising early indicators of response, which detect metabolic alterations while still reversible, include changes in serum neuraminic acid in vanadium poisoning, cholesterol in vanadium and carbon disulfide poisoning, and cystine in vanadium poisoning and other diseases.

The measurement of changes in conditioned reflexes has been proposed by a number of Russian investigators as a highly sensitive toxicologic tool. Thus far, behavioral patterns of response to toxic agents have not provided an interpretable measure of physiologic impairment.

The role of immunologic processes in the etiology and in the study of occupational diseases presents some serious challenges for the development of new immunologic techniques. SCHEEL, in this country, has shown that the toxic action of the quartz particle in silicosis may be the result of a foreign protein reaction in tissues (1960, 1954). He has demonstrated similar changes in the development of ozone lesions (1959) suggesting that the immunologic change induced by the altered protein structure may be a necessary and normal part in the fibrous healing process of a chronic lesion.

Allergic type responses are believed to occur in exposures to nickel, perhaps chromium, and in exposure to the vapors of the isocyanate monomers used in the preparation of diisocyanates. Such exposures lead to irritation of the respiratory tract, which may be followed within hours by asthmatic attacks. Opinion is mixed as to whether these asthmatic attacks are allergic in origin, but the evidence suggests

that some persons develop hypersensitivity to the isocyanates after repeated exposures. Skin tests with guinea pigs have shown that the most widely used isocyanate monomer, toluene-2, 4-diisocyanate, is a weak skin sensitizer, and it is assumed that the same would be true of other polyisocyanates (1959).

Epidemiologic techniques

Final proof of the safety of materials or preventive measures in the use of materials rests on the long-range effects on man. For a variety of reasons, it is frequently difficult to obtain adequate and long-range studies of exposures in the in-plant situation. Such studies, when done by in-plant medical personnel, may not reach scientific journals because of real or imagined compensation problems which might ensue. MANCUSO (1959), through the use of statistics of the Federal Bureau of Old-Age and Survivors Insurance, has been able to select populations exposed to certain industrial conditions and match them with suitable cohort groups not similarly exposed. Such data can indicate probable sources of industrial hazard and pinpoint the needs for more detailed epidemiologic research.

In 1957, a national health survey was started by the Public Health Service providing for continued household surveys of illness in the United States. Figures on occupational relationship are expected to be available in 1964.

OCCUPATIONAL DISEASES

Dust diseases

Silicosis. In terms of compensation costs and prolonged disability, silicosis continues to be the greatest, single, recognized occupational disease problem in the United States. Because of the wide variation among the States in criteria for the compensation of silicosis, it is difficult to obtain meaningful national statistics. On the basis of a study of compensation claims in 22 States covering the five-year period 1950 to 1954, TRASKO (1956) estimated that 10,362 cases of silicosis had been compensated in one form or another in those States. While this population was primarily an elderly one, there were a number of new cases among workers who entered dusty trades after 1935, when extensive dust control programs were inaugurated in this country. Ten per cent allegedly received their entire dust exposure after 1935.

The Public Health Service recently undertook two additional epidemiologic field studies of silicosis. One study covered five plants engaged in the mining and processing of diatomite (1958). Chest X-ray examinations of 869 workers showed changes consistent with the diagnosis of pneumoconiosis in 9 per cent of the workers, and doubtful changes in an additional 9 per cent. Cristobalite is believed to be the noxious agent. Suitable dust control measures were recommended.

The second study, which is being conducted with the United States Bureau of Mines, seeks to determine the prevalence of silicosis and dust exposures in the metal mining industry. This study has been under way since 1958 with environmental evaluations and medical studies, including chest X-rays, lung function tests, and medical and occupational histories. The results of this study will not be available until late 1961, by which time it is anticipated that approximately 15,000 miners and 75 mines will have been examined.

SCHEPERS' recent review (1960) of the theories of the cause of silicosis emphasizes that little basic experimental work in silicosis has been reported in the United States since the last Saranac Symposium in 1954. SCHEPERS (1960) observes that, while amorphous silica synthetic dusts of submicron size can produce lesions, there are notable exceptions. He concludes that surface area *per se* cannot predict the pathogenic action of particulate silica. The strong correlation observed between the protein absorptive capacity and the pathogenicity of the subject dust suggests need for further study. He noted that the electrophoretic mobility of dusts correlates more distinctly with pathogenicity than does the heat of wetting.

Schepers' using submicron amorphous silica and beryllium salts, and GROSS *et al.*, using antimony trioxide, have demonstrated the progressive accumulation of lipids within pulmonary macrophages. For this reason, as well as the fact that certain lipids artificially introduced into the lung are capable of producing extensive fibrosis, Schepers feels that lipids cannot be dismissed in the etiology of the silicotic lesion and that the precise over-all role remains to be elucidated. Schepers' work has also strongly supported the view of Cole that arteriolar obstruction is one of the most important features of silicosis.

GROSS and his co-workers (1958) have advanced the concept that silica particles penetrate the lung interstitium without the aid of phagocytes, and that silicotic nodules are initiated by the proliferation of cells within or upon the alveolar wall. These become cell clusters that subsequently enlarge and become collagenized. This, of course, is contrary to the thesis advanced by VIGLIANI and PERNIS.

There are a number of unresolved problems in the effects of the inhalation of mixed dusts. VORWALD (1960) points out that iron oxide and silica often present radiographic changes of nodular pattern but may not involve pathologic changes of disabling nature. He cites studies supporting the view that inhaled pure graphite dust is biologically active in proportion to its free crystalline silica content. Whether the graphite itself inhibits or stimulates the effect of free silica is as yet undetermined. In any event, his studies demonstrate that excessive exposure to natural graphite dust produces a focal and diffuse fibrogenic pneumoconiosis in both human and animal subjects.

Talc pneumoconiosis. Postmortem findings on two men with a diagnosis of talc pneumoconiosis confirm the hazard of inhaling high concentrations of talc over a number of years. Each of these men had worked for 25 y shovelling talc, hydrous magnesium silicate, into pans and coiling rubber-coated cable on the layer of talc. Ninety per cent of the talc particles were less than $10\ \mu$ in size. The free silica content was stated to be less than 0.5 per cent. The talc contained little or no tremolite.

SEELER *et al.* (1959) report that the symptoms and physical findings in both these cases were of the type seen frequently in severe chronic pulmonary disease. The lung tissue showed a progressive replacement of normal lung parenchyma by fibrous tissue. There was narrowing and occlusion of bronchi and bronchioles, and many of the vascular and lymph channels were obliterated. Many birefringent needle-shaped particles (believed to be talc as a result of X-ray diffraction studies) were present in the areas of fibrosis. "Talc bodies" were not found.

Other pulmonary diseases. Farmer's lung is a serious and disabling disease due to the inhalation of dusty, moldy organic materials. It has been recently recognized in the United States, and its etiology is thought to be hypersensitivity to organic

dust or mold, mycotic infection, or chemical or mechanical irritation of dust. The disease typically occurs within hours of exposure and is characterized by dyspnea, fever, chills, cyanosis, and weakness. Complete recovery is usually attained in a few days to several weeks.

TOTTEN (1958) reports on two cases in which lung biopsies were performed. The essential histologic features were granulomatous pneumonitis and bronchiolitis with varying degrees of interstitial fibrosis, focal obliterating bronchiolitis, and emphysema.

While numerous cases of the simultaneous occurrence of lung cancer and asbestosis have been reported since 1935, few of the reports contain sufficient epidemiologic data to establish a valid association.

BRAUN and TRUAN (1958) reported an epidemiologic study of 6091 persons employed in the asbestos mines of Quebec in 1950 with a history of at least five years' exposure to asbestos. Their status was determined at the end of a six-year observation period. The authors concluded that these miners do not have a significantly higher death rate from lung cancer than do comparable segments of the general population.

A new type of potential inhalation hazard was noted by BERGMANN *et al.* in 1958. The authors reported two patients who developed a diffuse bilateral pulmonary infiltrate and hilar lymphadenopathy following the use of hair sprays. In both, the radiographically visible lesions disappeared about three months after use of the spray was discontinued. In one patient, a scalene lymph node was excised. It showed a foreign-body granuloma supposedly typical of those produced by the parenteral introduction of macromolecular substances.

Radiation

The growing uses of radiation in industry, agriculture, and medicine have stimulated vigorous activity to curtail harmful and unnecessary exposures. Numerous ordinances have been enacted and radiologic health programs have been established in various States to control radiation hazards. In the absence of more definitive information on harmful doses, extensive research is being carried out.

Radiation exposures in uranium mining. Among research activities on occupational radiation exposures, the United States Public Health Service since 1950 has been conducting an environmental and clinical study in uranium mines. Approximately 4000 miners have been covered by the study. The chief radiation hazard has been identified as radon daughter products, the invisible radioactive particles produced by the breakdown of the gas radon (1957). While findings of lung cancer among the uranium miners are not yet conclusive, evidence points strongly to a probable occupational etiology.

Exposures to thoron and daughter products. Public Health Service investigators have also studied exposures to air-borne thoron and thoron daughters which appear in the thorium decay chain analogous to radon and radon daughters of the uranium decay chain (1960). They report that the radiation dose from thoron alone is probably insignificant when compared to the dose which would be delivered by its daughters.

Bronchogenic carcinoma from radioactive cerium fluoride. CEMBER *et al.* (1959) report on the carcinogenic effects of cerium fluoride diffusely distributed in the lungs

of rats at several dosage levels. They suggest a more conservative figure for the permissible level of Ce^{144} in air, listed as $7 \times 10^{-9} \mu\text{c}/\text{ml}$.

Cataracts and ultra-high frequency radiation. COGAN *et al.* (1958) found that no cataracts developed in rabbits following exposure to ultra-high frequency radiation repeatedly applied in doses near the lethal level distributed over the whole body.

Chelating agent used in treatment of thorium and uranium exposures. From their treatment of four persons injured severely when 40 lb of thorium dioxide and a small quantity of uranium dioxide exploded, YOUNG and TEBROCK (1958) conclude that edathamil merits consideration in the therapy of uranium and thorium damage.

Dermatoses

Occupational dermatoses comprise about two-thirds of all occupational diseases for which compensation is paid in the United States. Their cost is estimated at well over \$150,000,000 to \$200,000,000 a year.

Allergic photo contact dermatitis from Promethazine. Phototoxic and photo-allergic reactions from many industrial chemicals have yet to be explored. EPSTEIN (1960) reports a severe exacerbation of occupational dermatitis, following accidental exposure of the patient's hands to sunlight after treatment with Promethazine cream. There is also suggested evidence that sensitivity to one of these compounds may stimulate allergic reactions to several others in this same chemical grouping.

Phototoxic bullae among celery harvesters. Vesicular and bullous dermatitis among celery harvesters has been described frequently as an allergic reaction to celery oil, and Italian investigators have demonstrated a photosensitizing chemical in celery. A recent study by the United States Public Health Service and the Michigan Department of Health (1960) revealed that the development of phototoxic bullae is due to a chemical produced by a fungous disease of the celery (pink-rot).

Phototoxicity, photoallergy, and photoskin tests. JILLSON and CURWEN (1959) have reviewed in detail the diagnostic use of the carbon arc lamp in which they employ a fixed distance of 6.5 in from the skin and therapeutic B carbon for a continuous light spectrum. The minimal erythema dose can be determined on each patient, and various wave lengths of light can be delineated by use of filters. These methods can be employed in differentiating phototoxic, photodynamic, photo-allergic, and ultraviolet light erythema zones in the diagnosis of dermatosis associated with light.

The "ruster" in industry. Rusting of metal by palmar sweat is a problem in the manufacture of tools, ball bearings, watches, locks, and electronic equipment. It has been demonstrated by British workers that high concentrations of chloride ion in sweat are primarily responsible for the rusting of metal surfaces.

BUCKLEY and LEWIS (1960) report that workers with this capacity can be identified, preferably at the time of the preplacement examination, with the use of polished metal plates or impregnated gelatin plates. Severe "rusters" usually have more than 150 m-equiv./l of chloride ion in their eccrine palmar sweat. Preventive techniques suggested include avoidance of excessive salt intake, frequent washing of the hands, working in a cool environment, and wearing of gloves.

Threshold reactions to primary irritants. HAEBERLIN and FOX (1959) in studies with guinea pigs, observed that the presence of a massive dermatitis may increase

the irritability of the skin in other locations. From other experiments with white male students, they concluded that the thickness and integrity of the horny layer may have considerable influence on the reactions of the skin to threshold concentrations of primary irritants.

Noise

The problem of industrial noise control has received considerable attention in the United States during the past five years. In 1955 a new publication, *Noise Control*, was introduced to inform investigators of work done in this field as well as sources of materials and equipment for noise reduction. An Industrial Noise Manual was published in 1958 following three years of study by the technical committee on industrial noise of the American Industrial Hygiene Association.

Illustrative of increasing efforts in noise control, one large insurance company recently established a new research laboratory to determine the sources, character, and intensity of noise produced from various types of industrial production equipment and to devise methods for noise reduction. Noise control and hearing conservation programs have been inaugurated in a number of large industrial plants.

The establishment of specific noise standards is difficult because of the complexity of the total noise problem. Standards groups are concerned not only with medical and technical considerations but also with many value judgements which must be made, such as cost, risk, numbers of persons involved, effects on the total industrial community, legislation, and over-all, long-term, total community planning. The need for protective criteria has been recognized in interim standards proposed which will encourage preventive measures.

Among recent research efforts, the United States Public Health Service has studied the effects of industrial noise on hearing in the Federal Prison Industries. Data reveal that exposures in the range of 80 to 90 dB, which is not an unusual condition in industry, cause some loss of hearing. It was found that those workers with exposures in excess of six months did not recover their complete hearing acuity.

Chemicals

The growth of the chemical industry has been phenomenal, one billion dollars being expended each year for expansion of its facilities alone. Over 500 new products are introduced to the market each year. The number of new chemicals has become so large that a monthly journal called *Index Chemicus*, devoted exclusively to listing new chemicals, was published in 1960 for the first time.

The high cost of toxicologic evaluation is illustrated by the expenditure by one company of more than \$400,000 on toxicity testing and methods for detecting nickel carbonyl. Two million dollars were spent for safety considerations in the design of nickel carbonyl units in the plant.

A review of the advances in experimental toxicology for the past five years shows that some attention has been directed to the newer metals, particularly those of the rare earth group and also indium. The metal carbonyls, cobalt, nickel and iron, have been given considerable study because of their increased use as organic catalysts.

Experimental toxicologic investigation of organic chemicals has revolved chiefly around plastics, their precursors and additives, as well as their pyrolytic

products. High-energy fuels from boron and nitrogen have been given detailed examination. A limited number of solvents and some of the newer lubricants and their breakdown products have undergone toxicologic evaluation.

More attention is also being directed to the concentration of chemicals in confined spaces. The United States Public Health Service is cooperating in nuclear submarine habitability studies. Atmospheric gas concentrations and particulates have been measured, and air ion content determined.

Attention is also being given to the development of new therapeutic agents for combating accidental insecticide poisoning in man and of prophylactic and therapeutic agents for treatment of metal poisoning.

LEGAL ASPECTS

In contrast to the lack of specific provision for the coverage of occupational diseases by the early workmen's compensation laws in the United States, today some coverage of occupational diseases is included in the laws of forty-eight States, the District of Columbia and Puerto Rico. The trend is towards the full-coverage pattern. Thirty-four of the laws now cover all occupational diseases, while eighteen others cover only listed or "schedule" diseases.

Certain recent federal legislative developments relate directly or indirectly to occupational health. Among these was the passage in 1960 of the Federal Hazardous Substances Labeling Act, designed to protect consumers from the misbranding of hazardous substances used in industry and in the home.

The Longshoremen's Act was enacted in 1959, empowering the United States Department of Labor to establish safety standards for longshoremen and shipyard workers. This law requires that employers meet minimum requirements in maintaining safe equipment and healthful working conditions.

Also in 1959, Congressional hearings were held for the first time on problems of employee radiation hazards and workmen's compensation. A major portion of the hearings was devoted to evaluating the protective standards of compensation laws with respect to the threat of radiation disability.

The Atomic Energy Act was amended in 1959 to provide for the establishment of the Federal Radiation Council. This council is to advise the President on radiation matters affecting health, including guidance in the formulation of radiation standards and in the establishment of programs of cooperation with States. Provisions were also made to permit increased State assumption of regulatory responsibilities in nuclear development.

OCCUPATIONAL HEALTH SERVICES

Factors in growth

There has been a steady growth in occupational health services in the past 20 years, resulting from influences such as legal compensation, concern for humanitarian factors, scientific and technical advances, and sick absenteeism and medical care costs to labor and management. These forces have contributed to the development of strong medical-engineering programs to control occupational disease hazards and to the evolution of broader preventive-oriented services directed at improving and maintaining the general health of the worker.

Responsibility for the provision of such services in the United States rests with industry, other groups, both governmental and private, largely confining their activities to research, information-education, consultation and catalytic stimulation of such services.

The Federal agency primarily responsible for the protection of the health of American workers is the United States Public Health Service. The Service's Division of Occupational Health plays a vital supportive role to State governmental agencies, industry, labor, and other groups concerned with the control of occupational diseases and the promotion of employee health. Through a continuous program of field studies and laboratory research, the Division develops an ever-increasing store of knowledge on the causes and prevention of occupational diseases. Through its technical assistance, training, and publications activities, the Division makes available the benefit of this knowledge to all groups concerned and, in addition, provides consultation on the solution of special problems and the establishment of effective occupational health programs.

Responsibility for the enforcement of occupational health practices in industry rests with State agencies. At present there are seventy-six occupational health units located in forty States and in thirty-three local health departments.

In the United States, occupational health functions are carried out by a multidisciplinary team, including the industrial physician, the industrial hygiene engineer, the industrial nurse, the chemist, the toxicologist, and other specialists. In small industries the nurse generally carries the major responsibility for occupational health.

In recent years, labor has expressed a greater degree of interest in occupational health. Most labor unions in the United States have used the funds made available through collective bargaining for the purchase of medical and hospital expense insurance or to finance their own union programs. The programs range from diagnostic services to comprehensive health care for workers and their families. A few union health centers conduct studies of the work environment or provide an industrial hygiene engineer to investigate job exposures suspected of adversely affecting health.

Official agencies are assuming more responsibilities for the health of people who work, over and beyond activities relating to the control of occupational disease. For many years, state health departments have extended their chest X-ray programs to industry. Now tests are being included for cancer, diabetes, and glaucoma. While local health departments are showing more interest in extending their public health services to industry, no definite pattern is yet discernible.

The voluntary health agencies, such as the National Tuberculosis Association and the American Heart Association, are directing more attention to occupational health. In 1959, for example, the National Health Council, composed primarily of voluntary health agencies, held its first forum on the health of people who work. As an outgrowth of the forum, explorations are being made of how voluntary agencies can contribute to the furtherance of occupational health.

Of significance to occupational health is the changing pattern of financing medical care. At present, health insurance programs made available and paid for through the worker's place of employment cover more than 37 million employees and their 57 million dependents, a total of 94 million people.

As the number of companies supporting comprehensive health insurance coverage for their employees has increased, the line between occupational health and medical care has sometimes tended to blur. The higher employee payments under general sickness insurance plans has prompted on some occasions the treatment of all possible cases as non-occupational. At the same time the potential of such programs for early detection and diagnosis has not been realized by those plants that are financially unable to provide preventive services in the occupational setting.

An immediate effect of the growth of health insurance coverage has been to place increased emphasis on the prevention of non-occupational diseases, since these represent the greatest share of sickness costs and absenteeism. As the cost of illness of all types becomes a management concern, management may logically come to view the early recognition of occupational factors as an opportunity to apply primary preventive measures and reduce the overall illness cost.

Although this trend may augur well for the expansion of occupational health services in industry, there is presently a serious deficiency of occupational health services in small plants, employing under 500 workers, which constitute over 99 per cent of industrial establishments in the United States and employ over two-thirds of the non-agricultural labor force.

It should be pointed out, however, that workers in small plants do not lack adequate medical resources in their community. At the present time, in the United States there is one physician for every 750 persons. Recent data from the National Health Survey show that employed individuals visit their physicians on the average of 4.5 times per year.

Concern with the need to bring occupational health services to the small plant rests primarily on two reasons. First, the primary category of occupational health services, the medical and engineering control of occupational disease hazards, must obviously be carried out within the confines of the plant. Second, the other category, representing a wide range of preventive health services, not necessarily related to the job, but nonetheless important in terms of general worker health, reduction of absenteeism, and maintenance of productivity, should desirably be provided at or through the plant if at all feasible. Of the 4.5 physician visits per employed person per year referred to previously, visits for "general checkup" accounted for 8 per cent of the visits. A health program carried on at or through the place of work can be a strong force both in providing certain of these preventive services and in motivating the worker to use the other resources available to him in protecting and improving his health.

Medical developments

There has been a clearer discernment and redefinition in recent years of the role of periodic examination and screening programs in industry. For example, although some companies continue to emphasize executive examinations, it has been amply demonstrated that the incidence of most diseases is no greater in executives than in other workers.

The value of periodic examinations continues to be debated, due perhaps to inadequate attention to all of the variables that need to be measured. A cataloging of the defects that are found means little unless related to the corrections that are

made in those defects. Ideally, one should know what effect such programs have upon useful longevity. Even if these programs cannot be shown to increase life expectancy, there remain many intangible factors that are difficult to quantitate and which may have equal or greater importance. What does it mean to the employee to have someone genuinely interested in his health? Does this interest cut down the employee's "worry time"? Is he better off psychologically, a better adjusted and therefore a more productive employee in his job and in his community?

Although still subject to controversy, the screening program—representing a useful first step in the detection of disease—has been finding wider acceptance in industry and elsewhere. Illustrative of industrial multiple screening programs, the Industrial Health Council of Greater Atlanta (Georgia), using a healthmobile, served about 10,000 white collar and industrial workers during the first year of operation. More than half of the persons tested had significant findings and were referred to their own physicians. Tests utilized were height and weight; chest X-ray; blood tests for diabetes, syphilis and anemia; urine albumin; blood pressure; and vision.

Advances are continuing in the development and evaluation of tests for specific conditions, together with activities to promote the use of those which prove successful.

Among recent efforts to develop early, sensitive, diagnostic techniques, studies are underway to apply the well-known Papanicolaou cytology technique for uterine cervical cancer to the detection of cancer of other sites. Some findings suggest that cytology can be useful in the early diagnosis of cancer of the genitourinary system. Studies of heart diseases and related conditions point, for example, to the development of an improved agent for the lowering of blood pressure in patients with hypertension.

The benefits of some of the tools developed from this broad research may be compounded by applying them to occupational exposures. Thus, as an extension of the Papanicolaou technique, the United States Public Health Service has used bronchial washings in its study of uranium miners as an aid in detecting early cancer of the lung. In addition, work is underway to develop specific tests for occupational agents, to permit the detection and control of harmful exposures before irreversible damage occurs. Thus far, the work of the United States Public Health Service has indicated that vanadium poisoning can be detected by changes in the fingernails long before any clinical symptoms appear.

TRAINING

Concomitant with increased activity in occupational health, there has been a trend for professional specialization in this field. In 1955, the specialty of occupational medicine was established for physicians under the American Board of Preventive Medicine of the American Medical Association. The American Industrial Hygiene Association and the American Conference of Governmental Industrial Hygienists are presently working toward the establishment of a certification for industrial hygienists.

In the nursing field, professional organizations and official agencies are encour-

aging both the development of specialized, advanced courses of study and the integration of occupational health in the undergraduate curriculum. Of the 14,200 registered professional nurses employed full time in American industry, 352 have academic degrees. Of this number, only 150 have 30 or more hours of public health nursing training. Another 188 nurses have 30 or more hours of training in public health nursing but no academic degree.

DISCUSSION

Occupational health in the United States has undergone three major stages of development. It has become more highly specialized in the area of impact of the working environment on health; it has broadened its base to include alignment with other environmental health programs; and it has served as a focus for the application of preventive health practices to a segment of the gainfully-employed population.

Irregular growth has characterized occupational health programs in this country. Because of the lack of adequate legal compulsion, over half of the industrial establishments in the country do not have basic industrial hygiene safeguards. Yet, some of the larger establishments, in providing comprehensive diagnostic and preventive services, have extended their activities far beyond the occupational disease control program that might conceivably be required by law.

Similarly, while some official agencies have strong occupational health programs, most are underbudgeted and understaffed.

The scope and growth of occupational health services will undoubtedly be influenced by the comprehensive health insurance coverage now being provided to increasing numbers of employees.

The direction of occupational health programs will also be largely affected by the changing nature of the occupational health problems. In contrast to earlier acute, large scale poisoning, today's occupational health hazards are less apparent and more insidious and devious in their manifestation. They may be grouped in three classes:

- (1) the old problems which doggedly persist, either because known controls are not conscientiously applied, or because additional basic knowledge is needed to reduce further the incidence of disease.
- (2) new problems arising from the interaction between the worker and his physical, chemical, and biological environment.
- (3) a grey area of chronic diseases where the occupational relationship is suspected and which will require deeper probing.

Still another significant change affects the course and progress of occupational health. There has been a heightened awareness of the effects of the growing chemical world surrounding us and of the consequences of exposures to radiation and other agents of technologic prowess. Although this man-made environment encompasses the whole of our civilization, increasing attention is being given to the occupational factor. It is in the in-plant environment where many of the toxic pollutants now threatening the air and water of communities throughout the nation are first spawned. The industrial worker is first exposed to the plethora of chemicals that find their way into home use. More and more, it is being recognized that industry

is the incubator for problems of more far-reaching consequence, and that alert, scientifically sound and completely unbiased investigations of occupational health problems can often prevent illness or at least provide the basis for later community-wide investigations.

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THE PRODUCTION OF PHOSPHINE WHILE MACHINING SPHEROIDAL GRAPHITE IRON

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Abstract—Phosphine is produced in small quantities during the machining of spheroidal graphite iron. A quantitative investigation on a single roll turning machine is described. Concentrations were low but higher than the maximum allowable concentrations suggested by the American Conference of Governmental Industrial Hygienists and the Soviet Commission which reported in 1960. These concentrations appeared to be dependent on the process carried out and the relative humidity of the atmosphere; swarf lying around the machine contributed substantially to these concentrations. The hazard can be adequately controlled by efficient exhaust ventilation and collection of swarf into a suitable medium.

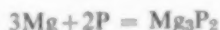
INTRODUCTION

SPHEROIDAL graphite iron is a ductile form of iron containing graphite in a spheroidal form rather than the flake form found in ordinary cast irons. When certain special inoculants are added to the melt the graphite is distributed as spheroidal nodules. These do not concentrate stresses in the same way as the flakes and hence do not lower the ductility of the iron in comparison with that of steel. (Figs. 1 and 2.)

Two principal methods of causing the graphite to be distributed as nodules have been described. Firstly, in hypereutectic irons by making a ladle addition of cerium or mischmetal (an unseparated reduction product from a natural mixture of rare earths) and, secondly, by controlled additions of magnesium to hypoeutectic and hypereutectic irons. In the latter method the magnesium is added to the iron in the form of a copper or nickel alloy which reduces its very great activity and raises its boiling point, which under normal circumstances is the same temperature as that of molten iron from the furnace (1100 °C). HOLDEMAN and STEARS (1949) and DONAHO (1949) found that nickel-magnesium and copper-magnesium alloys containing 10-20 per cent of magnesium were satisfactory for this purpose. 1-2 per cent of this alloy is added to the ladle at the time of tapping. These inoculations leave a small but significant magnesium content in the range 0.04-0.10 per cent. When spheroidal graphite irons are freshly fractured or machined they evolve a characteristic odour similar to that of acetylene. This odour is said to be more pronounced when the freshly exposed surfaces come into contact with a moist atmosphere. This odour is familiar to persons working in the Iron and Steel industry, as it is evolved from certain reducing slags used in basic lined furnaces when these slags are allowed to cool in contact with air. The smell associated with commercial acetylene is not that of pure acetylene, which has a rather sweetish ether-like odour,

but rather that of impurities which include hydrogen sulphide, phosphine and arsine.

BROWN (1951) studied this characteristic odour. In the early stages there had been speculations regarding the existence of carbides in this type of iron which would hydrolyse to give this odour. Such speculations, however, assume that the odour is that of acetylene. Brown presumed that the odour is primarily due to phosphine and postulated that a hydrolyzable phosphide is formed in iron by the direct action of magnesium (or other elements) with phosphorus:



which, when the metal is fractured, is hydrolyzed by moisture in the air to phosphine:



This study appeared to be theoretical and not based on experiment.

This early work established the fact that there was a characteristic odour when spheroidal graphite iron was freshly fractured or machined and presumed that it was primarily due to phosphine.

It was known that phosphine is a highly toxic gas in low concentrations but, as there were no complaints, the matter remained of academic interest only until 1955 when it was reported that illness had arisen among workmen engaged in turning spherical graphic iron rolls in the Saar. The affected workmen complained of pains in the eyes, nose and stomach with some nose-bleeding, and, as only small amounts of phosphine were found by qualitative testing, it was believed that the reported illness arose mainly from the inhalation of fine dust from the machining operation. This dust was believed to be magnesium phosphide, which on contact with moisture present in the nose and throat, would generate phosphine (hydrogen sulphide is also mentioned) in concentrations sufficient to give unpleasant effects.

TOXICITY OF PHOSPHINE

Phosphine is an extremely toxic gas, the maximum allowable concentration of which for an 8 hr period is given as 0.05 p.p.m. by the American Conference of Governmental Industrial Hygienists and 0.07 p.p.m. by the Soviet Commission which reported in 1960. Fully investigated cases of poisoning by phosphine are rare in the literature and have been reviewed by HARGER and SPOLYAR (1958). The mechanism of intoxication has been deduced from this rather small number of cases and reports on animal exposures. It is necessary to appreciate that phosphine poisoning is not a common diagnosis to make unless the hazard is apparent; moreover, the symptoms are common to a number of other affections and, on this account it is likely that a number of cases have been missed. Clinical and pathological evidence of phosphine poisoning is scanty and the cases described in the literature have been acute ones after exposure to relatively high concentrations. The symptoms arising from phosphine poisoning include:

1. an oppressed feeling in the chest,



FIG. 1. Grey iron shewing flake graphite $\times 100$.

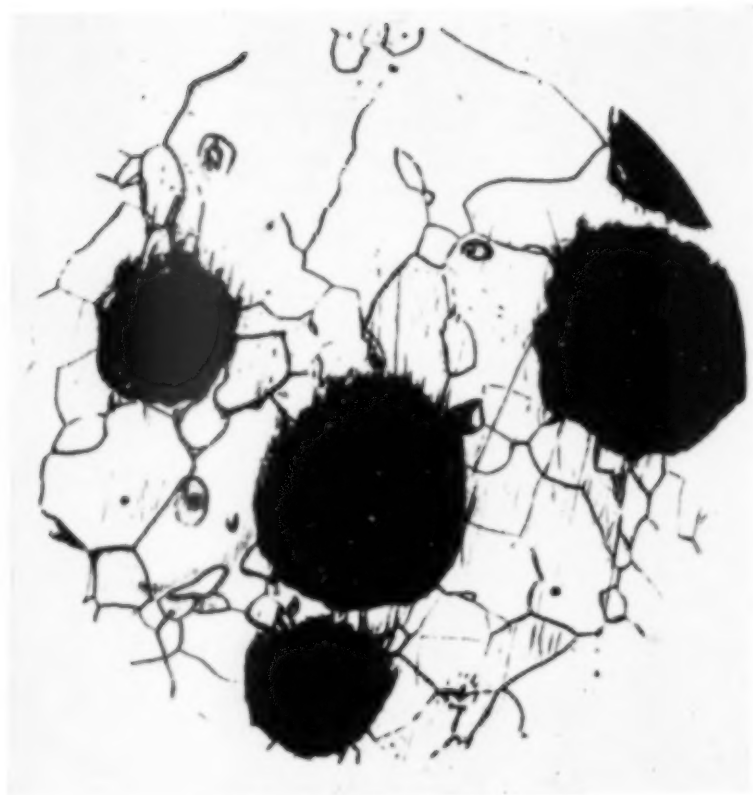


FIG. 2. S.G. iron fully ferritic, etched $\times 250$.

2. dryness of the throat with a feeling "as if your tonsils were like large apples" and a difficulty in swallowing,
 3. headache,
 4. vertigo,
 5. abdominal pain,
 6. anorexia, nausea, vomiting,
 7. severe diarrhoea and tenesmus,
 8. thirst,
 9. general debility,
 10. lachrymation,
- followed by—
11. staggering gait,
 12. convulsions,
 13. coma and death.

These symptoms would appear to be those of an anti-cholinesterase i.e. they are the muscarinic effects of an accumulation of acetyl-choline. An important contrary point is that bradycardia and meiosis have not been described in any clinical accounts, nor have any of the nicotinic effects of acetyl choline, for example, muscular fasciculations affecting the tongue, eyelids, face, neck, and extrinsic eye muscles. Phosphine does not appear to be an irritant and the lachrymation could well be due to the muscarinic effect of acetyl choline on the sphenopalatine ganglion. At post-mortem there is found to be considerable exudation into the alveolar spaces and bronchioles, which once again could be a muscarinic effect rather than that of an irritant.

Epistaxis has figured as a symptom of alleged poisoning by fume from S.G. iron. This has not been described in other forms of true or possible phosphine poisoning, apart from cases arising among 14 men laying a concrete foundation, described by PHILLIPS (1954). In these cases it was found that the cement produced 6 p.p.m. of phosphine, which was thought to originate from calcium phosphide.

It seems clear that there is no obvious haemolysis such as is found in arsine poisoning. CLERENS (1946) kept two pairs of white rats (of unstated age) in cages within the generating rooms of an industrial acetylene plant for 238 days, at the end of which period they were killed and examined. Prior to their death the animals remained apparently healthy. At post-mortem there was hyperplasia of the thyroids, some small areas of calcification in the muscles of the neck and some slight inflammatory changes in the lungs. These findings would appear to have no bearing on poisoning by phosphine. Furthermore the work is rather invalidated as no details are given of the diet taken by the rats during the period, and there is no record of the composition of the atmosphere of the room.

In fact it is not known whether phosphine was actually present.

MEINHARDT LOWENTHAL (1949) compared the clinical, pathological and toxicological aspects of an actual case of phosphine poisoning with results obtained from animal experiments with varying concentrations of phosphine. Pronounced blood and lymph stasis accompanied by brain and liver lesions of a special nature occurred as a result of subacute intoxication. Subchronic poisoning produced degenerative

changes of the ganglion cells indicating that phosphine must be considered as a central nervous system poison. Reference has already been made to the suggestion that phosphine reacts with the red cells, damages vascular walls and causes osmotic disturbance of permeability giving rise to nervous manifestations from central nervous system damage. The same mechanisms are thought to cause liver lesions. In the cases described by PHILLIPS (1954) symptoms were not severe and no haemolysis or jaundice was observed.

In some toxicological studies on the effect of zinc phosphide on certain animals by JOHNSON and VOSS (1949) it was found that this substance most likely reacted with hydrochloric acid in the stomach to produce phosphine which was absorbed, and which was the actual toxic principle. Rats were exposed to 0.02 per cent zinc phosphide in their food for one month, at the end of which time they were killed and a histopathological examination made. In the liver several zones of injury were evident, especially about the central and peripheral lobular areas which exhibited injury sufficient to kill the parenchymal cells. For variable distances extending from these areas the parenchymal cells were disintegrated or in the process of disintegration as manifested by the failure of cell nuclei to stain while the cytoplasm was coagulated. A great increase in numbers of fibroblastic nuclei was observed within and around the portal canal areas in sections taken from rats receiving more intensive exposure. The alveolar capillaries of the lungs were congested with blood, numerous areas showing haemorrhage or serious exudation into the alveolar spaces. Considerable mononuclear infiltration was seen around the smaller bronchi and bronchioles of some sections. No infallible signs of damage were observed in sections of spleen, pancreas, intestine, adrenal, heart, kidney, ovary, or testis. The fact that phosphine is partially excreted by the lungs might explain why lesions are found only in the liver and lungs.

In these experiments phosphine would be absorbed in the intestine, carried to the liver by the portal circulation and thence to the lungs by way of the right side of the heart and pulmonary arteries. Since, in the chronically poisoned rats, the concentration of zinc phosphide is low, and that of phosphine proportionate, the lungs might well remove the phosphine so effectively that organs other than the liver and lungs would not be seriously harmed.

Assessment of the available literature would appear to show that the serious systemic effects of phosphine are due to a direct action on the cells of the central and autonomic nervous systems, possibly supplemented by haemorrhagic effects in the brain and elsewhere, and an action on the parenchyma of the liver, probably due to vascular and haemorrhagic effects. There is no suggestion of a direct haemolytic action and chronic phosphine poisoning has never been described. If the latter existed at all, which seems unlikely, it would be as tenuous an entity as chronic carbon monoxide poisoning.

Present investigation

In view of the paucity of knowledge regarding the nature and possible health hazard of the fumes generated during the turning of spheroidal graphite iron it was decided to make a full scale investigation at one of our foundries where S.G. iron castings had been produced and machined since 1953.

The investigation was started on the basis that S.G. iron produces an "acetylene-

like" odour when machined, which was said to cause nausea, loss of appetite and irritation of the eyes amongst some of those people exposed to it.

A preliminary inspection of the machine shop at the Foundry in question was carried out. The shop is 350 ft long by 110 ft with a roof sloping laterally from 43 to 31 ft. This gives a volume of 1,359,750 ft³. The shop is arranged broadly into four parts

1. roll turning shop,
2. machine shop,
3. heavy machine shop,
4. fitting and erecting.

There are two railway entrances at the South end and two pedestrian entrances at the North end. (Fig. 3.)

At the first inspection there was no abnormal smell in the general atmosphere. At the time only one machine was turning S.G. iron and a distinct "acetylene-like" odour was noticed in the immediate vicinity of this machine. The swarf lying around the machine had the same odour when picked up and smelled close to the nose. A substantial amount of dust (which appeared to be black and carbonaceous) was seen to come from the cutting tool, more so than when steel or grey cast iron are turned. It should be noted that the maximum number of machines turning S.G. iron at any one time was six and this prevailed throughout our investigation.

Swarf was taken at the time and our initial experiments were directed to determining what gases were present on a qualitative basis. Steam was passed over the swarf into solutions of silver nitrate and potassium permanganate giving rise to substantial reduction. This could be caused by any reducing gas but qualitative tests on the reduced solutions showed the presence of phosphate suggesting that phosphine was contained in the mixture of gases which had come from the iron turnings. Tests for hydrogen sulphide and acetylene were negative and as no arsenic could be detected in the reduced solutions, we assumed no arsine was present.

The chemical confirmation that the gas evolved is phosphine and the development of a method for its quantitative determination is described in Part II of this paper. The method ultimately evolved was used throughout the field investigation with minor modifications. A qualitative analysis of the dust that is produced showed that it consists mainly of carbon (Table 1) and the results of a particle count and size analysis are shown in Table 2.

TABLE 1. ANALYSIS OF DUST SAMPLES

Volume of air sampled (l.)	Rate of flow (l. hr)	Dust Collected mg.	Carbon %	Iron (total) %	Phosphorus
550	140	37	63.4 63.4	24.1	0.030
1200	300	137	49.1	43.9 44.2	0.026 0.028

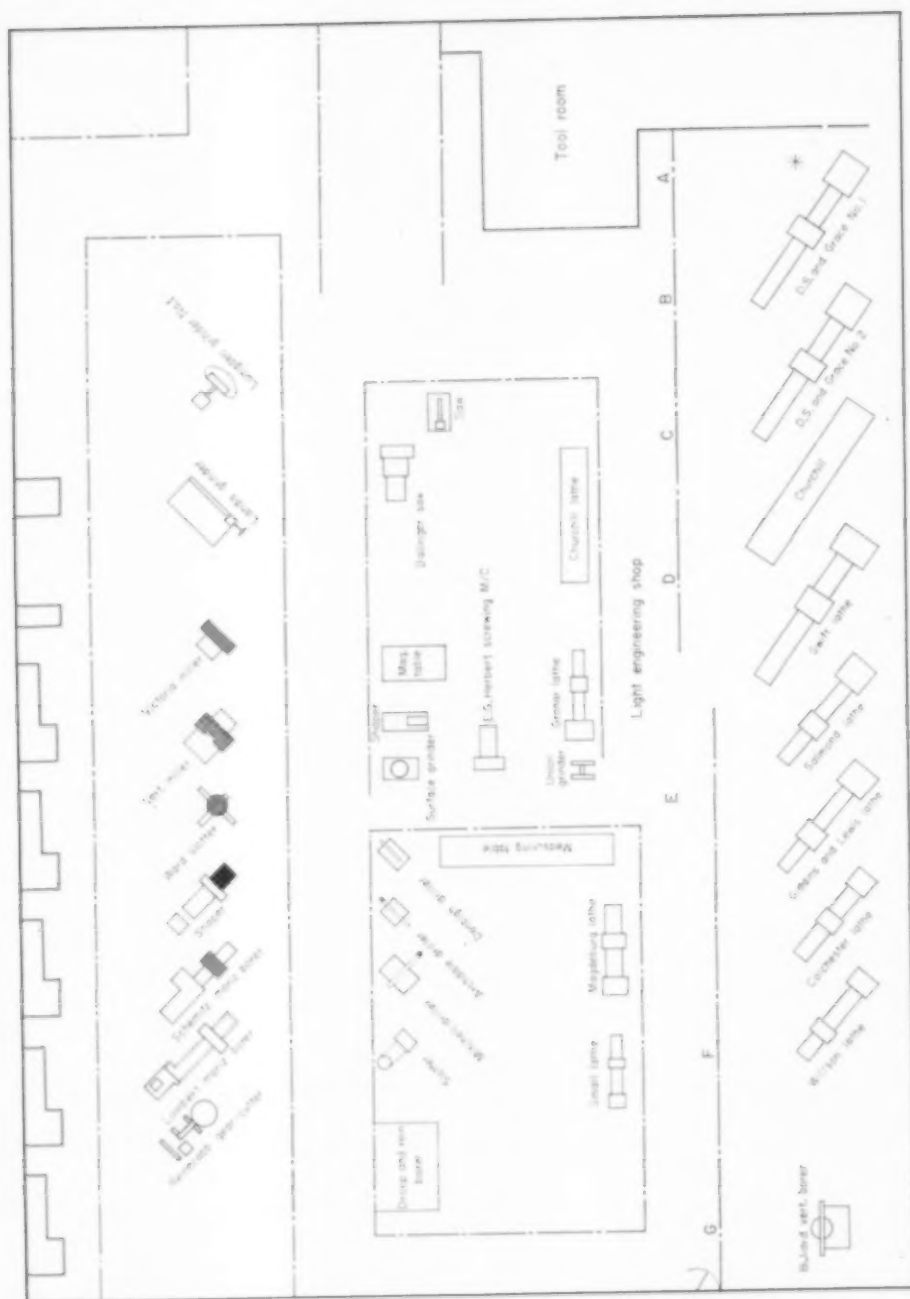


FIG. 3. Machine on which investigation was carried out (*), and arrangement of shop.

TABLE 2. COUNT AND DISTRIBUTION OF PARTICLE SIZES OF DUST COLLECTED BY THERMAL PRECIPITATOR

Total Count (7.5 μ)($\times 950$, direct vision) 285 particles/cm³.($\times 2000$, Vickers projection) 359 particles/cm³.

SIZE RANGE (total counted 412)

Size (microns μ)	No.	%
7.5	16	3.9
6.0	10	2.4
4.5	13	3.1
3.75	27	6.5
3.0	23	5.6
2.4	18	4.4
1.8	32	7.8
1.2	36	8.8
0.6	101	24.6
0.3	136	33.1

TABLE 3. ANALYSIS OF S.G. IRON ROLL USED IN EXPERIMENTS

Carbon	..	2.80%
Sulphur	..	0.007%
Manganese	..	0.23%
Silicon	..	2.91%
Phosphorus	..	0.080%
Nickel	..	2.00%
Magnesium	..	0.083%
Arsenic	..	0.020%
Tin	..	0.009%

The ratios of carbon, phosphorus, and iron were not related to those in the S.G. iron roll (Table 3—typical Roll Analysis). This was to be expected as carbon is a brittle, low density element which is more likely to be evolved as a dust. The same probably applies to the phosphorus constituent of the dust but in this case the fine particles are probably chemically active and lose some of their phosphorus by reaction with atmospheric moisture. Quantitative spectrographic analysis showed the presence of nickel, magnesium, manganese, silicon and iron.

In view of these results and because the presence of phosphine had been definitely established, it was not felt necessary to continue with a detailed examination of the dust clouds produced in a workshop although a typical series of konimeter counts can be seen in Table 4.

Investigation in machine shop at Machynys Works

In order to get standard conditions as far as possible, a single roll turning lathe was selected for our survey. This was a Dean Smith & Grace lathe turning 4 ft and 8 ft rollers of 12 in diameter. The capacity of the machine is given in Table 5. The

TABLE 4a and b. KONIMETER COUNTS

Table a

Konimeter	Speed	Cut	Position taken	Rough/Finishing
Slide 1 1-30	56 rev/min (approx.)	$\frac{1}{4}$ in	At roller opening	Inside boring from commencement. 1st rough cut. Wetting on outside of roller.
Slide 2 1-30	do.	do.	do.	do.
Slide 3 1-29	do. do.	do. do.	do. do.	do. do.
* Count 30 = General atmosphere immediately after boring—6 ft 0 in from machine.				
Slide 4 1-30	56 rev/min	$\frac{1}{8}$ in	At roller opening	Inside bore from commencement. 2nd rough cut. Wetting on outside of roller.

Table b

Slide No. 1		Slide No. 2		Slide No. 3		Slide No. 4	
Count	Group	Count	Group	Count	Group	Count	Group
1	7	1	9	1	7	1	8
2	6	2	8	2	6	2	5
3	3	3	8	3	6	3	7
4	1	4	9	4	4	4	8
5	3	5	8	5	8	5	8
6	1	6	7	6	6	6	8
7	1	7	8	7	6	7	4
8	1	8	7	8	8	8	9
9	1	9	7	9	5	9	6
10	4	10	8	10	6	10	8
11	1	11	7	11	4	11	6
12	2	12	8	12	4	12	5
13	1	13	8	13	1	13	9
14	6	14	8	14	4	14	8
15	4	15	7	15	4	15	6
16	8	16	8	16	8	16	5
17	4	17	8	17	9	17	6
18	4	18	8	18	8	18	5
19	9	19	8	19	7	19	5
20	6	20	8	20	5	20	5
21	1	21	7	21	4	21	5
22	1	22	6	22	7	22	6
23	2	23	7	23	6	23	6
24	1	24	7	24	6	24	6
25	1	25	7	25	6	25	7
26	7	26	8	26	3	26	4
27	8	27	8	27	3	27	5
28	5	28	7	28	3	28	4
29	8	29	8	29	2	29	6
30	9	30	8	30	1	30	8

TABLE 4b—continued.

Groups	Particles per cm ³
1	50-100
2	100-200
3	200-300
4	300-400
5	400-500
6	500-600
7	600-700
8	700-800
9	800-900

machine was situated in the machine shop in the position marked on the diagram (Fig. 1). Originally it was hoped to make a statistically valid study relating air concentrations with all the variables. Owing to unexpected difficulties this was not possible, but it is believed that the results were sufficiently revealing to provide a basis for action.

TABLE 5. AIR MOVEMENTS TAKEN ON ELEVEN SEPARATE OCCASIONS WITH A HOT WIRE ANEMOMETER

	A	B	C	D	E	F	G
	30	36	42	60	72	73	74
	30	36	60	72	72	74	76
	29	42	59	60	71	73	120
Direction	36	60	72	42	72	74	75
of movement	36	37	30	21	30	31	84
North to South	30	42	59	59	72	73	74
	28	30	31	23	42	59	73
	31	36	37	41	59	72	75
	17	71	8	74	12	30	73
	30	31	23	36	74	29	36
	6	12	41	41	120	74	41
MEAN	25.7	39.4	42.0	48.0	63.2	60.2	72.8

METHOD

The method of chemical analysis used was essentially that described in Part II of this paper. As far as sampling was concerned the only difference was that the flow rate was measured by the pressure drop across a capillary tube calibrated against a wet meter. This was necessary as sampling in a works requires a high degree of compactness and portability. The whole sampling train was contained in a wooden box apart from the electric pump.

Glass beads were used in the Drechsel bottles to start off with but it was found that we got a maximum absorption without them and as they were difficult to clean after each sample was taken it was decided to dispense with them.

Controls were run with each batch and occasionally the incremental method of adding phosphate to both test and central bottles was used. In spite of all precautions 47 samples were discarded because of their doubtful validity due to

contamination or incomplete absorption. They represented about 25 per cent of all the samples. The sampling time varied from 5 min to 2 hr with a modal time of 30 min. The results showed no relation to sampling time, suggesting that there were no great peaks or depressions of concentration.

The volume of air sampled at one time varied from 2.2 to 36.0 l.

RESULTS

These have to be related to a number of variables on the machine and in the environment operating at the same time. The variables encountered include the following—

Air movement around the machine

Temperature

Humidity

Machine speed (rev/min)

Depth of cut

Whether coolant used or not

Outside or inside bore

} these are dependent on the process carried out and the results are divided broadly into roughing and finishing

and the results will be assessed in relation to each of them.

Air movement around machine

Within the workshop as a whole the air movement was extremely variable owing to a number of factors. These included the wind speed outside, whether the doors were closed or not, and whether there was local heating or not. The air-movements around the machine being investigated were fairly constant by virtue of its situation close to the wall away from the main airstream. In the main gangway on the west side there was a well marked downward gradient from the north end to the machine under investigation, as can be seen in Table 6.

TABLE 6

Relative Humidity	Less than 70%	More than 70%
Mean phosphine (p.p.m.) concentration (at less than 12 in from cutting edge).	Mean 1.25 (22 readings) Range < 0.01-4.60	Mean 1.70 (19 readings) Range 0.6-3.60

The positions A, B, C etc., are marked on the diagram of the shop at Fig. 3.

Thus the lowest air movement was in the vicinity of the machine under investigation and the variation around the machine would be insufficient to affect our results.

Air temperature

This varied from 14 °C to 28 °C but bore no relation to the air concentrations of phosphine. It is a necessary factor in determining the concentration of the gas in p.p.m. but it plays no significant part in the production of these concentrations.

Humidity

The relative humidity was taken with a hair hygrometer (degree of error 30–90 per cent \pm 3 per cent R.H.), at the same time as each of the samples. This factor is largely dependent on the external climate but in view of its theoretical importance in the production of phosphine from the postulated magnesium phosphide in S.G. iron it was decided to look at the humidity factor more closely. When inside bores are being performed on rollers a coolant consisting of one part of oil to forty parts water is used on the outside of the roller.

At no time is the coolant used directly on the cutting tool. It was found that the relative humidity was higher close to the machine when coolant was used than the relative humidity 8–10 ft away (e.g. 65 per cent close to the machine; 58 per cent 9 ft away). This was to be expected but a comparison between forty-five readings taken near the machine when coolant was used and forty-five readings when it was not, on different days, showed that the mean relative humidity when it was used was 73 per cent and 66 per cent when it was not, i.e. a difference of only 7 per cent. Nevertheless this small difference in the mean relative humidities appears to have played some part if Tables 6 and 7 are examined.

TABLE 7

Coolant	Not used	Used
Mean phosphine (p.p.m.) concentration (at less than 12 in from cutting edge).	Mean 0.87 (23 readings) Range < 0.01–3.63	Mean 2.26 (21 readings) Range 0.60–4.60

The smaller differences apparent when the phosphine concentrations are taken in relation to relative humidities than when they are compared with and without coolant are probably due to a local increase in humidity which it was impossible to measure with the instruments at our disposal.

Operations performed on machine

The complete machining of a roller takes from 14 to 15 hr. The operation is carried out in four stages both outside and inside the roller—

- 1st rough cut
- 2nd rough cut
- 3rd rough cut
- 1st finishing cut
- 2nd finishing cut
- polishing

The machinists work on a 3-shift basis (6–2, 2–10, 10–6).

For convenience it was decided to divide the operations into two parts—roughing and finishing (including polishing), whether these operations were carried out on the outside of the roller or on inside bores. The depth of cut, feed and machine speed varied in relation to the process being performed. The higher speeds and

small depths of cut being associated with finishing; the lower speeds and greater depths of cut with roughing operations.

From Tables 8 and 9 it can be seen that the lower speeds and deeper cuts produce a higher mean concentration than the faster speeds and smaller cuts, i.e.

TABLE 8. MACHINE SPEEDS

	48-54 rev/min	63-94 rev/min
Mean phosphine concentration (p.p.m.) less than 12 in from cutting edge.	1.70 (21 readings) Range < 0.01-4.60	0.83 (24 readings) Range < 0.01-2.40

TABLE 9. DEPTH OF CUT

	10- $\frac{1}{16}$ in.	$\frac{1}{8}$ in.- $\frac{3}{16}$ in.
Mean phosphine concentration (p.p.m.) less than 12 in from cutting edge.	0.52 (24 readings) Range < 0.01-2.20	2.00 (18 readings) Range 0.63-4.60

roughing tends to produce greater amounts of gas than finishing (including polishing).

There was no reason to suppose that the concentrations would vary to any great extent if they were produced from inside bores or outside.

In actual fact, there was a substantial difference amongst readings taken at less than 12 in from the cutting tool (Table 10). This was probably because of the concentration of the gas within the bore of the roller and the fact that the sampling probe was usually placed close to the roller opening.

TABLE 10

	Inside	Outside
Mean phosphine concentration (p.p.m.)	1.94 (26 readings) Range 0.37-4.60	0.94 (23 readings) Range < 0.01-3.63

In the breathing area of the operative, the position was reversed but to a less extent (Table 11); with so few readings there is little significance in this result.

Distance from cutting tool

A progressive diminution in the concentration of phosphine would be expected as samples were taken further from the cutting tool, which we assumed to be the source of the gas. The expected diminution is apparent but it is not as great as would be expected. This led us to believe that there might be another source of the gas which was causing the flattening of the concentration slope. Nineteen samples were

taken 3 in-4 in from the swarf lying on and around the machine. The mean concentration of these readings was 2.66 p.p.m. with a minimum of 0.47 p.p.m. and a maximum of 9.37 p.p.m. This was obviously a potent source of the gas and a laboratory experiment was carried out.

An attempt was made to estimate the amount of phosphine given off by fresh swarf over a measured period of time under two different conditions of humidity. This was carried out by estimating the concentration produced in two closed containers by similar amounts of swarf at constant temperature (30 °C) and relative humidities of 37 per cent and 100 per cent respectively.

CONTAINER A: Relative humidity 37 per cent.

CONTAINER B: Relative humidity 100 per cent.

In container A (R.H. 37 per cent) it was found that 68.8 g of swarf gave off 0.0100 mg of phosphine in 96 hr.

In container B (R.H. 100 per cent) it was found that 70.1 g of swarf gave off 0.0585 mg of phosphine.

As a result of this work there was no doubt that swarf was producing phosphine in relatively substantial quantities and was certainly contributing in no small measure to the concentrations found around the lathe.

In view of the findings it was decided there was a hazard, although it was not considered a serious one. If it had been serious there would have been well-defined cases of poisoning amongst the operatives in the period during and before this investigation was carried out. Nevertheless it was considered necessary to install protective measures.

TABLE 11

	Inside	Outside
Mean phosphine concentration (p.p.m.)	0.80 (14 readings) Range < 0.01-1.54	1.09 (19 readings) Range < 0.01-5.30

TABLE 12

	Under 12 in	12-24 in	Breathing area 4-6 ft
Mean phosphine concentration (p.p.m.)	1.43 (35 readings) Range < 0.01-5.15	1.00 (20 readings) Range < 0.01-5.3	0.65 (16 readings) Range < 0.01-0.95

Protection

Personal protection, in the form of a canister respirator, was never considered seriously. It is always the last line of resort and only used when all other methods have been proved useless. There were two problems—the gas given off at the cutting tool and that given off from the swarf. They had to be treated separately.

Gas given off at cutting tool

The obvious way of eliminating the gas produced at this source was by local

exhaust ventilation. Although the dust is harmless it was decided that the exhaust should also have sufficient capacity to remove this at the same time. A dustmaster DM 151/27-F.H.5 extraction apparatus, made by Dallow Lambert and Company Limited, was obtained. This had a fan capacity of 2300 ft³/min from a 3½ h.p. motor; was fitted with an acoustic duct and a 4½ in diameter inlet adaptor. Twenty feet of 4½ in diameter flexible piping was attached to it and the opening of this was placed approximately 8 in from the cutting tool. The face velocity at the duct opening was 3700 linear ft/min. This was reduced to only 50 ft/min, 6 in away. It was realized that the apparatus probably had greater capacity than was needed and that certain refinements were required to increase its efficiency, e.g. suitable hood design, more accurate positioning of duct opening, optimum length of flexible piping. As far as we were concerned we wanted to find a principle which would work and which was reasonably adaptable if necessary. The refinements were beyond our scope and would have to come from engineers.

Twenty-two readings were taken with the apparatus and sampling heads in the positions shown in Fig. 4. This was closer than the normal breathing area of the operative. The results can be seen in Table 13.

TABLE 13

Concentrations of phosphine (p.p.m.)	Readings
Nil	14
0.12	3
0.24	1
0.38	1
0.43	1
0.85	1
1.02	1
Mean: 0.15	22 readings

This was not absolutely satisfactory but it was felt that it was sufficiently so to warrant the use of this method, refinements being carried out by the engineering department and further samples being taken by ourselves in relation to these refinements. It is worthy of note that all the high readings were obtained when rough cuts ($\frac{1}{8}$ – $\frac{1}{4}$ in.) were being performed and when there was a relative humidity of more than 67 per cent. A contribution to these high readings may be made by phosphine emanating from the freshly cut area of the roller.

Experiments were carried out to see if it would be possible to absorb phosphine by simple methods within the extractor. Anything more than the simplest methods were rejected as they would have required more maintenance than they were worth. Unfortunately the "simple" methods were not completely efficient and would not have been practicable with the velocities passing through the extractor without substantially re-designing the machine. The methods tried were with heat alone (100 °C) which is known to destroy phosphine, charcoal absorption and absorption on to silica gel. These methods tried alone or in combination never gave more than 70

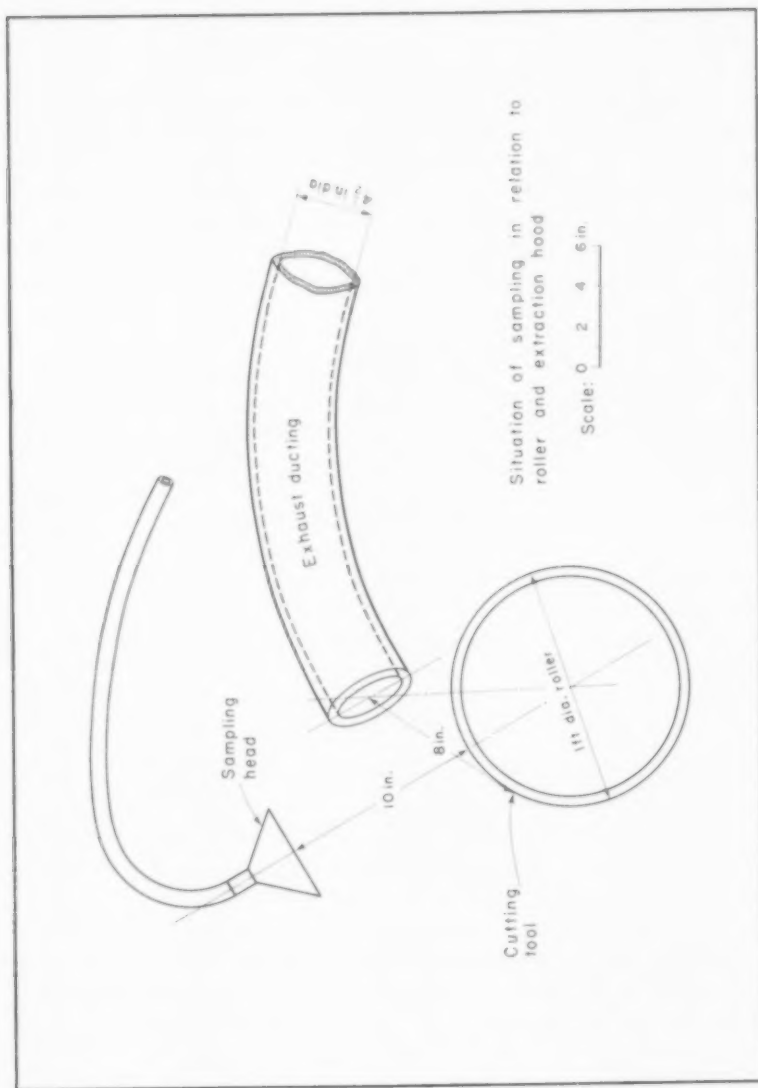


FIG. 4. Situation of sampling in relation to roller and extraction hood.

per cent absorption with flow rates as low as 18 l. an hour. Chemical methods were not considered in view of the maintenance problems involved.

Gas given off from swarf

The substantial amounts of gas produced from the swarf demanded attention. It was clearly not possible to provide exhaust ventilation for the whole of the area in which swarf collected. In view of this it was decided to attempt to absorb the phosphine at source by immersing the swarf in a 1 per cent wt./vol. solution of potassium permanganate. A tray was designed which moved along with the tool head collecting the swarf as it was formed. One per cent wt./vol. potassium permanganate was contained in the tray. Once again this was not entirely satisfactory although no phosphine was produced from the tray. The main reason for dissatisfaction was that the tray did not collect all the swarf and was also not suitable for all operations on the lathe. Once again this was a question of engineering design and beyond our scope. It is believed that the principle is essential in controlling any possible hazard.

Clinical

Operatives described certain symptoms including dryness of the throat, tightness of the chest, irritation of the eyes, loss of appetite and nausea. These were subjective and rather non-specific and cannot be considered to be of scientific value. Nevertheless, they might have been suggestive in a state of affairs which was inevitably imprecise.

An accident in our laboratory gave higher concentrations of phosphine than would ever be met in industry and symptoms that developed in two of us included a well-marked feeling of oppression in the chest, dizziness and a definite nausea. Samples of urine taken over the next twenty-four hours from one of us showed no haematuria or haemoglobinuria due to haemolysis or increased capillary permeability.

CONCLUSIONS

1. Phosphine gas was produced during the machining of spheroidal graphite iron.
2. The concentrations were low and appeared to be dependent on the process carried out and the relative humidity of the atmosphere.
3. Swarf lying around the machine contributed in no small way to the concentrations obtained in the breathing area of the operatives.
4. One machine, such as has been investigated, in a large well-ventilated workshop is not particularly hazardous to normal people. One machine in a small badly ventilated workshop could give rise to a much greater hazard.
5. The hazard can be adequately controlled by efficient exhaust ventilation and efficient collection of swarf into a suitable medium.

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THE DETERMINATION OF PHOSPHINE IN AIR

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INTRODUCTION

THE method for determining the phosphine content of air employed in Part I was the outcome of a laboratory investigation into several possible techniques. This paper describes the experimental work undertaken and the Appendix presents a detailed description of the sampling and analytical procedures finally recommended.

EXPERIMENTAL

Because of the necessity for developing sampling as well as analytical techniques it was essential to experiment with an atmosphere drawn from the vicinity of a lathe in which Spheroid Graphite iron rolls were being turned. For this purpose an S.C. cast iron roll 6 in diameter and approximately 14½ in long (typical analysis given in Table 3, Part I) was aligned in a 7 in centre Cardiff lathe and turned at 27 rev/min using a cemented carbide tip roughing tool with a feed of 0.005 in and 0.008 in depth of cut. A pronounced acetylenic smell was noticed in the vicinity of the lathe, especially when cutting fluid was used.

Spot test reactions using impregnated papers showed that the gas evolved was not acetylene or hydrogen sulphide, but a strongly reducing gas such as phosphine. The results of these tests, together with those obtained in checking the response of spot papers to acetylene and H₂S are given in Table I.

TABLE I. EXPERIMENTS WITH SPOT-TEST PAPERS

Test	Vicinity of Lathe	Acetylene (cylinder)	H ₂ S (Kipps)
Lead acetate paper ..	No reaction	No reaction	Black
Silver nitrate paper ..	Black	No reaction	Black
Mercuric chloride paper ..	No reaction	No reaction	Black
Amm. cuprous chloride ..	No reaction	Red	—

Subsequent experiments aimed at determining the reducing gas (phosphine) concentration in the atmosphere around the cutting tool involved drawing measured volumes of air at known rates through absorbents contained in Drechsel bottles. Figs. 1(a) and 1(b) show the apparatus finally devised. Polluted air is drawn into the funnel by an electrically driven pump and is filtered by an ignited asbestos plug to

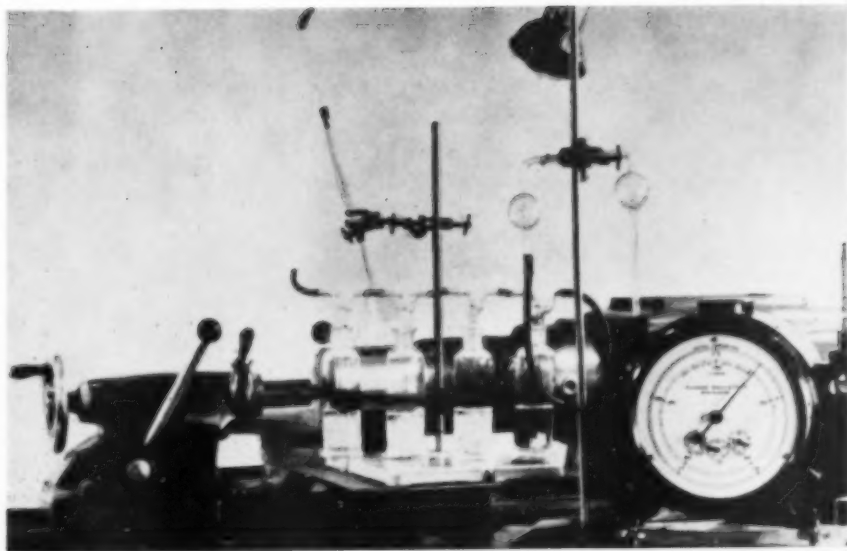


FIG. 1(a). Sampling Equipment.

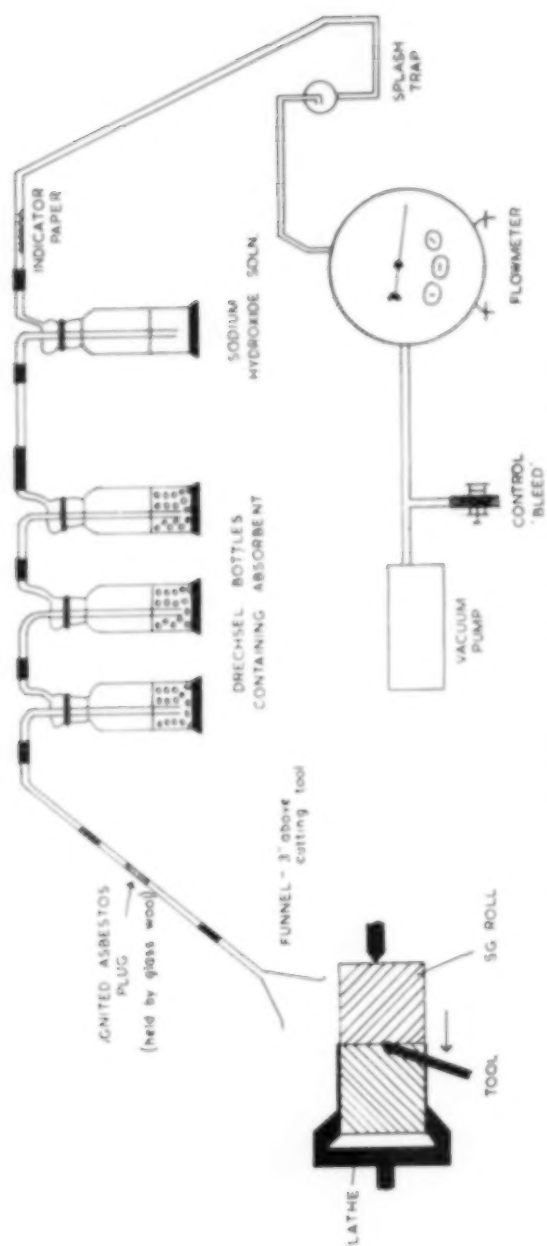


Fig. 1(b). Diagrammatic arrangement of sampling equipment.

prevent the ingress of dust-containing phosphorus. It then passes through three Drechsel bottles containing glass beads and liquid absorbent; a fourth bottle containing sodium hydroxide solution is necessary when using volatile absorbents such as bromine water or hypochlorite solution to avoid severe attack of the flowmeter and pump. A check on the efficiency of the "guard" bottle is provided by litmus or methylorange indicator papers placed as shown. The flowmeter (Alexander Wright) is protected against caustic spray by first passing the gas through a splash head.

The development of the method can be regarded as consisting of two distinct parts:

- (a) The investigation of a suitable absorbent, suitable vessels and optimum sampling rates for efficiently absorbing the phosphine and
- (b) The accurate measurement of the phosphine reaction products in the absorbent.

Sodium hypochlorite, bromine water and potassium permanganate solutions were tested as probable absorbents, but because of the urgency of the project, it was not possible to examine systematically the relative merits of each solution in turn. In attempting to obtain a satisfactory method as quickly as possible, a new absorption experiment often had to be started before obtaining the results from the previous one and hence it was not always possible to incorporate any modification immediately. However, for convenience, the experiments are presented as a logical development without attempting to keep to the chronological order.

1. EXPERIMENTS USING SODIUM HYPOCHLORITE SOLUTION AS ABSORBENT

A search of the literature revealed that sodium hypochlorite solution had been used for the absorption of phosphine present as an impurity in acetylene gas produced from certain carbides (BRAMELD, W. (1945) and EDWARDS, A. H. (1947)), and a method by Brameld seemed suitable for preliminary experiments. The phosphine is absorbed in a solution of hypochlorite (2.5 per cent avail. Cl) containing 1 per cent sodium bicarbonate, which after boiling to expel dissolved acetylene is diluted to a known volume. The excess hypochlorite of an aliquot is destroyed by first boiling with hydrochloric acid and then adding potassium iodide, any free iodine being titrated with thiosulphate. Urea is added to inhibit decomposition of free thiosulphate and the phosphate determined by conversion to phosphomolybdate followed by stannous chloride reduction to molybdenum blue.

In order to obtain efficient absorption of the phosphine, it was necessary to employ hypochlorite solutions which finally contained much higher excess hypochlorite/phosphate ratios than those used by Brameld. Experiments on synthetic solutions showed that a relatively large amount of excess hypochlorite was detrimental. Thus the blue molybdenum colour was not stable and often changed rapidly to green and finally yellow, presumably due to incomplete destruction of the hypochlorite. Modification of reagent concentrations (molybdate and stannous chloride solutions) failed to give promising results.

A paper by LEVINE *et al.* (1955) deals with the molybdenum blue reaction and

the determination of phosphorus in the presence of silicon, arsenic and germanium. It was decided, therefore, to calibrate this procedure on the Spekker and, if successful, to adopt this finish to the hypochlorite absorption technique. As shown in Table 2, the results were very encouraging and this finish was therefore used for all subsequent work; details are included in the proposed method (Appendix).

TABLE 2. CALIBRATION OF SPEKKER, ILIFORD 608 FILTERS, Hg VAPOUR LAMP

mg P added	E ₁ cm
0	0.015
0.010	0.108
0.020	0.185
0.030	0.269
0.040	0.371
0.050	0.435

Each 50 ml contains:

2 ml conc. hydrochloric acid

5 ml ammonium molybdate soln. (2 per cent)

0.3 ml stannous chloride (0.5 per cent)

Unsatisfactory results were obtained when this finish was applied to synthetic solutions containing hypochlorite as well as phosphate, presumably due to incomplete destruction of the hypochlorite. Later experiments in which nitric acid was used to destroy the sodium hypochlorite as in the method by EDWARDS were also unsatisfactory and it seemed that the phosphate must be separated from the hypochlorite solution prior to its colorimetric determination.

In the paper by LEVINE *et al.* (1955), details are given for the determination of phosphorus in sea water in which the phosphate is concentrated by precipitation as aluminium phosphate using aluminium hydroxide as a carrier. This technique was therefore investigated.

Fifty ml of sodium hypochlorite solution (2.5 per cent avail. Cl) containing 1 per cent sodium bicarbonate were diluted to 250 ml and to suitable aliquots were added known amounts of phosphate solution. After acidification 5 ml of a standard aluminium solution (1 ml = 1 mg Al) were added and the solutions heated to boiling and made ammoniacal. The precipitates were filtered on to a Whatman No. 541 paper and after washing with ammonium chloride solution (1 per cent) and

TABLE 3. PHOSPHATE DETERMINATION AFTER ALUMINIUM SEPARATION FROM HYPOCHLORITE

mg P added	50 ml NaOCl diluted to 250 ml			
	10 ml aliquot			5 ml aliquot
	E ₁ cm			E ₁ cm
0	0.020	0.020	0.030	0.030
0.015			0.160	
0.030	0.280	0.281	0.301	
0.050			0.455	0.415

finally once with water, were dissolved in 4 ml of hydrochloric acid (50 per cent v/v) and the molybdenum blue colour developed as recommended. The results obtained (given in Table 3) indicated that this modification could be successfully applied to the method and that the next step was to test the efficiency of hypochlorite as an absorbent.

Results of the lathe experiments are given in Table 8. Tests A, B and C proved unfortunately that the hypochlorite solution used does not give satisfactory absorption unless slow sampling rates are employed. The phosphate contents of the individual Drechsel bottles were determined using the aluminium separation technique just described.

2. EXPERIMENTS USING POTASSIUM PERMANGANATE AS ABSORBENT

Potassium permanganate has been used as absorbent for phosphine by MÜLLER who was interested in determining the phosphine content of synthetically prepared atmospheres for toxicological experiments. In the method quoted the gas is slowly passed through three small absorption vessels, each containing 10 ml of N/100 potassium permanganate and 1 ml of sulphuric acid (5 per cent v/v). After decolourizing the permanganate with oxalic acid the phosphate is determined as molybdenum blue using ammonium molybdate and hydroquinone reducing agent.

Ten ml of N/100 potassium permanganate were just decolourized with N/100 oxalic acid and the solution diluted to 100 ml. Known volumes of phosphate solution were added to 20 ml aliquots and the molybdenum blue colour developed as before using stannous chloride for the reduction. A similar series was prepared, in which an aluminium separation was incorporated. The results (given in Table 4)

TABLE 4. PHOSPHATE DETERMINATION IN PRESENCE OF PERMANGANATE, WITH AND WITHOUT ALUMINIUM SEPARATION

10 ml KMnO_4 (N/100) + 10 ml oxalic acid (N/100) \rightarrow 100 ml
20 ml aliquots taken

mg P added	Direct (no sepn.) E_1 cm	Al sepn. E_1 cm
0	0.025	0.030
0.0125	0.125	—
0.015	—	0.150
0.025	0.223	—
0.030	—	0.287
0.0375	0.323	—
0.050	0.430	0.440

show that no separation is necessary when permanganate is used as absorbent. When, however, this method was applied to workshop tests, it was found that N/100 permanganate was unsatisfactory for complete absorption. In test D each Drechsel bottle was charged with 20 ml of N/200 permanganate, and 1 ml of sulphuric acid (5 per cent v/v); in test E, 40 ml N/100 permanganate and 4 ml of sulphuric acid

(5 per cent v/v) but, as can be seen from Table 8, complete absorption was not achieved and it was decided to test bromine water.

3. EXPERIMENTS USING BROMINE AS ABSORBENT

The advantage of bromine is that it can readily be removed from solution by boiling or destroyed by ammonia in the separation of phosphate with aluminium. Calibration experiments were made using synthetic solutions comprised of 50 ml of bromine water and known amounts of phosphate solution. These were gently boiled to separate most of the bromine and after destroying the last traces with ammonia, they were diluted to 100 ml. Aliquots of 50 ml were gently evaporated to 30 ml and the phosphate determined as described in Section I. These experiments did not incorporate an aluminium precipitation; the results are given in Table 5. How-

TABLE 5. PHOSPHATE DETERMINATION IN BROMINE EXPERIMENTS

mg P added (final 50 ml)	E ₁ cm
0	0.023
0.015	0.135
0.030	0.260
0.050	0.443

ever, a general check on the method was provided by further analyses embodying aluminium phosphate precipitation.

The results of Test F (Table 8) showed bromine to be an efficient absorbent but due to its volatility, most of the bromine rapidly migrated from the first Drechsel bottle during sampling. At this stage a critical assessment of the three absorbents was made as follows, culminating in the development of the use of permanganate.

4. COMPARISON OF THE DIFFERENT ABSORBENTS

The tests A to F revealed certain useful information regarding the three absorbents.

- Bromine water appeared to be the most efficient absorbent as judged by the relative amounts of phosphate detected in the separate scrubbers (not by the total amount which would be dependent upon conditions prevailing in the workshop at the time of test, i.e. humidity, draughts). However, bromine is dangerous for field tests and moreover is highly volatile.
- Sodium hypochlorite solution is limited to low flow rates, gives rise to highly variable blanks and also necessitates an aluminium phosphate separation.
- The potassium permanganate solution was an inefficient absorber but might be improved by increased strength.
- Drechsel bottles are usually readily available and the ease of charging and emptying is an advantage. However, they cannot be classified as efficient absorbents.

It was decided to carry out a further series of tests using the same solutions and, by standardizing the conditions of flow rate and volume, obtain more comparative values regarding their respective efficiencies. At the same time results were obtained from experiments using N/10 permanganate solution. In an attempt to obtain better overall efficiency the Drechsel bottles were packed with glass beads. The values obtained are tabulated as Tests G to J (Table 8).

Under these conditions it was found that all solutions except the weaker permanganate gave reasonably complete absorption and that, as before, bromine could only be used for a limited time. The most significant result was that the stronger (N/10) permanganate solution completely absorbed the phosphine and this was confirmed by further trials (Tests K and L). The proposed method described in the Appendix therefore involves absorption by N/10 permanganate since this substance is innocuous (a great advantage for field trials) and does not require separation of the phosphate by aluminium. The use of stronger permanganate with the corresponding increase in acidity did not affect the Spekker calibration but it is important to minimize excess oxalic acid since otherwise fading of the molybdenum blue occurs.

Excellent results are obtained if the technique outlined in the Appendix is used; results of a typical calibration are given in Table 6.

TABLE 6. SPEKKER CALIBRATION (PROPOSED METHOD)

mg P added (final 50 ml)	E ₁ cm
0.000	0.020
0.015	0.145
0.030	0.280
0.040	0.348
0.050	0.437
0.050	0.430

5. CONFIRMATION THAT EVOLVED GAS IS PHOSPHINE

Reference has already been made to the use of spot tests for determining the nature of the gas(es) arising from the machining of S.C. iron. These tests, whilst showing the presence of a reducing gas which is not hydrogen sulphide, do not eliminate the presence of arsine and silane which might possibly arise from arsenic and silicon present in the iron. Moreover, both arsenate and silicate (like phosphate) can produce a molybdenum blue coloration and hence might interfere with the determinations. It was decided, therefore, to test the polluted air for arsine and silane.

During previous investigational work an apparatus had been devised for collecting most of the gas evolved at the machined surface of the metal so that, if necessary, the total gas produced could be related to the amount of machined area and other characteristics. This apparatus consisted of a metal drum rigidly fixed about the cast iron roll and having an outlet tube which could be fitted via absorption vessels

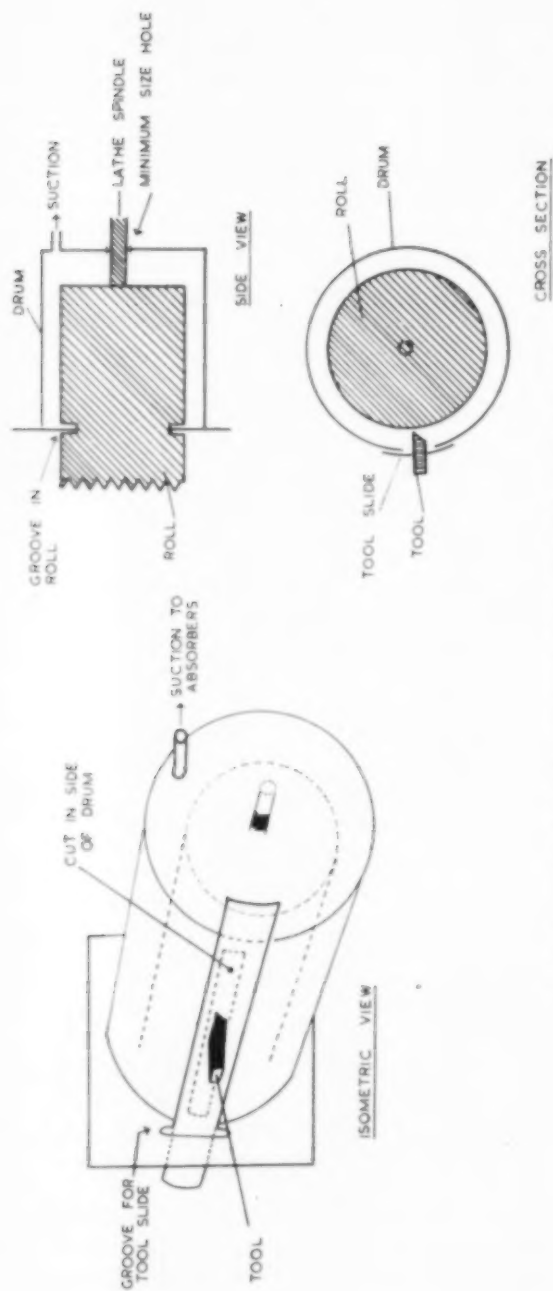


Fig. 2. Apparatus for collecting most of gas evolved during machining.

to the suction pump. The drum was not intended to form an air-tight cover for the roll, but was so constructed that the vacuum applied to draw the gases through the absorption vessels would be sufficient to maintain a slightly negative pressure within it. Figure 2 gives an illustration of the equipment.

By this means an appreciable quantity of the evolved gas was collected in three bubblers containing N/100 permanganate. After discharging the permanganate with oxalic acid the solutions were diluted to 100 ml and suitable aliquots taken and the phosphate determined as already described. This experiment was carried out before the proposed method (using stronger absorbent) had been developed and as shown in test M (Table 8) the amounts collected in the individual bottles are almost identical. However, the purpose of the trial was only to collect an amount of gas sufficient for examination purposes.

The arsenic determination was carried out in two ways, viz.

- (a) A direct Gutzeit determination after sulphuric/nitric acid treatment and
- (b) Separation of any arsenic by distillation with hydrochloric acid and cuprous chloride followed by a Gutzeit determination on the filtrate after acidity adjustment.

Aliquots of the first and third Drechsel bottles gave results which suggested that about 0.015 mg As was present in the total volumes. The method was checked by determining the arsenic content of aliquots to which known amounts of arsenic had been added. However, the Gutzeit determination depends upon the visual comparison of stains and any errors are magnified when scaled up, so that the above result should be interpreted as indicative of order only.

Experiments showed that arsenic solutions gave the molybdenum blue reaction under the same conditions as phosphate but that the depth of the colour was much lower. Thus 0.05 mg of arsenic/50 ml gives a Spekker reading of 0.175 compared with values around 0.410 for the equivalent amount of phosphorus.

A second series of experiments showed that any arsine arising was too low to affect the phosphine determinations. In these, the phosphate was precipitated from aliquots of the absorbents as aluminium phosphate, dissolved in hydrochloric and sulphuric acid, and any arsenic volatilized by evaporation to fumes with hydrobromic acid. After dilution, the phosphate was determined in the usual way, and

TABLE 7. EXPERIMENTS IN ASSESSING POSSIBLE SILICON AND ARSENIC INTERFERENCE

Experiment	Sample	Conditions	E ₁ cm corrected	mg. PH ₃ equivalent per absorber
a	10 ml Trap 1	Al pptn. HBr treatment	0.255	0.311
b	10 ml Trap 2	Al pptn. HBr treatment	0.220	0.268
c	10 ml Trap 3	Al pptn. HBr treatment	0.185	0.226
d	10 ml Trap 2 + 0.05 mg Si + 0.05 mg As	Al pptn. HBr, HF treatment	0.220	0.268
e	as d	Al pptn. only	0.295	0.360
f	10 ml Trap 2	Al pptn. HBr, HF treatment	0.232	0.283

TABLE 8. WORKSHOP TESTS

Test	Collection rate (l./hr)	Total vol. sampled (l.)	Drechsel No.	Absorbent	Dilution and Aliquot	Optical density—blank E_1 cm	Method	mg $\text{PH}_3/\text{l.}$ (per absorber)	Total PH_3 (mg/l.) (average)	Comments
A	72	18	1st 2nd	50 ml NaOCl " " "	250/50 250/100 250/50 250/100	0.121-0.040 = 0.081 0.131-0.020 = 0.111 0.075-0.040 = 0.035 0.075-0.020 = 0.055	Al separation " " "	0.0027 0.0020 0.0011 0.0010	0.0034	Incomplete absorption
B	120	60	1st 2nd	50 ml NaOCl " " "	250/50 250/100 250/50 250/100	0.215-0.040 = 0.175 0.322-0.020 = 0.302 0.078-0.040 = 0.038 0.151-0.020 = 0.131	Al separation " " "	0.0018 0.0016 0.0005 0.0007	0.0024	Incomplete absorption
C	40	40	1st 2nd 3rd	50 ml NaOCl " " "	100/50 100/50 100/50	0.202-0.060 = 0.142 0.102-0.060 = 0.042 0.055-0.060 = Nil	Al separation " " "	0.0009 0.0003 Nil	0.0012	
D	40	40	1st 2nd 3rd	20 ml N/200 KMnO ₄ " " "	100/20 100/25 100/40 100/20 100/25 100/40 100/20 100/25 100/50	0.072-0.020 = 0.052 0.092-0.023 = 0.069 0.102-0.025 = 0.077 0.055-0.020 = 0.035 0.070-0.023 = 0.047 0.090-0.025 = 0.065 0.051-0.020 = 0.031 0.062-0.023 = 0.039 0.090-0.025 = 0.065	Direct Al separation Direct Al separation Direct Al separation "	0.0008 0.0008 0.0006 0.0005 0.0006 0.0005 0.0005 0.0005 0.0004	0.0017	Incomplete absorption
E	10	15	1st 2nd 3rd	40 ml N/100 KMnO ₄ " "	100/20 100/20 100/20	0.075-0.020 = 0.055 0.052-0.020 = 0.032 0.035-0.020 = 0.015	Direct " "	0.0022 0.0015 0.0006	0.0043	Incomplete absorption
F	12	14.4	1st 2nd	50 ml Br ₂ water "	250/50 250/50	0.140-0.040 = 0.100 0.040-0.040 = Nil	Direct "	0.0045 Nil	0.0045	Test stopped when bromine almost completely exhausted from 1st D.B.

Test	Collection rate (l./hr)	Total vol. sampled (l.)	Dreschel No.	Absorbent	Dilution and Aliquot	Optical density—blank E_1 cm	Method	mg PH_3 /l. (per absorber)	Total PH_3 (mg/l.) (average)	Comments
G	20	20	1st 2nd 3rd	50 ml NaOCl " "	100/50 100/50 100/50	0.358-0.040 = 0.318 0.068-0.040 = 0.028 0.050-0.040 = 0.010	Al separation " "	0.0042 0.0004 Negligible	0.0046	Glass beads used in this and all subsequent tests
H	20	18	1st 2nd 3rd	50 ml N/100 KMnO_4 " "	100/25 100/50 100/50	0.140-0.020 = 0.120 0.175-0.020 = 0.155 0.080-0.020 = 0.060	Direct " "	0.0035 0.0022 0.0009	0.0066	Incomplete absorption
I	20	8	1st 2nd 3rd	50 ml sat Br_2 water " "	100/25 100/25 100/25	0.130-0.041 = 0.089 0.043-0.041 = 0.002 0.041-0.041 = Nil	Direct " "	0.0060 Negligible Nil	0.0060	Test stopped after 8 l. due to loss of bromine
J	20	20	1st 2nd 3rd	50 ml N/10 KMnO_4 " "	100/25 100/25 100/25	0.272-0.020 = 0.252 0.050-0.020 = 0.030 0.025-0.020 = 0.005	Direct " "	0.0067 0.0008 Negligible	0.0075	
K	20	20	1st 2nd 3rd	50 ml N/10 KMnO_4 " "	100/25 100/25 100/25	0.170-0.020 = 0.150 0.061-0.020 = 0.041 0.025-0.020 = 0.005	Direct " "	0.0040 0.0011 Negligible	0.0051	
L	20	20	1st 2nd 3rd	50 ml N/10 KMnO_4 " "	100/25 100/50 100/25 100/50 100/25 100/50	0.183-0.020 = 0.163 0.340-0.020 = 0.320 0.044-0.020 = 0.024 0.068-0.020 = 0.048 0.030-0.020 = 0.010 0.040-0.020 = 0.020	Direct " " " " "	0.0043 0.0043 0.0006 0.0006 0.0003 0.0003	0.0052	
M	20	10.5	1st 2nd 3rd	20 ml N/100 KMnO_4 " "	100/25 100/5 100/25 100/5 100/25 100/5	0.603-0.020 = 0.583 0.145-0.020 = 0.125 0.555-0.020 = 0.535 0.125-0.020 = 0.105 0.470-0.020 = 0.450 0.110-0.020 = 0.090	Direct " " " " "	0.285 mg PH_3 /absorber 0.305 0.261 0.251 0.220 0.220	Experiments to confirm absence of hydrides of silicon and arsenic	

gave results (Table 7) in good agreement with those originally obtained (Test M Table 8).

In regard to silicon interference it was found that silicon solutions alone did not produce a molybdenum blue colouration under the recommended conditions.

To conclude the investigation into possible interference by arsenic and silicon, a final series of experiments (Table 7) was made, based on the published method LEVINE, H. *et al.* (1955) for the determination of phosphate in the presence of arsenic and silicon. Arsenic is volatilized by hydrobromic acid as above after hydrofluoric acid treatment to remove any silica from the aluminium precipitate. These experiments proved that silicon and arsenic were not present in appreciable quantities (compare experiments b and f with original). Experiment d, which corresponds to additions of 0.5 mg Si and 0.5 mg of As to the original Drechsel proved the effectiveness of the hydrobromic and hydrofluoric acid treatments—experiment e without this modification giving high results.

Since in all the previous experiments phosphate had been determined colorimetrically, it was felt that gravimetric confirmation would be desired. Using the "enclosed atmosphere" technique, a relatively large amount of gas was absorbed in N/10 permanganate which was decolourized with oxalic acid and diluted to 100 ml. A 2 ml aliquot was taken and the phosphate determined colorimetrically, giving a value of 2.04 mg of phosphorus per 100 ml.

The phosphate in a 50 ml aliquot was precipitated as ammonium phosphomolybdate $(\text{NH}_4)_3\text{PO}_4 \cdot 12\text{MoO}_3$ which was filtered and dried at 110 °C. The weight 0.0632 g corresponds to a phosphorus content of 2.08 mg/100 ml.

The ammonium phosphomolybdate was converted to lead molybdate in the usual way, the weight found (0.1482 g) being in good agreement with the theoretical amount (0.1485 g).

CONCLUSIONS

A method has been developed for the determination of phosphine in air. It is suitable for field tests such as might take place in machine shops etc., where spheroidal cast iron is being worked and does not involve the use of dangerous absorbents such as bromine. Moreover, the analytical technique is simple and can be used by relatively inexperienced staff.

Data are presented which give an indication of the phosphine level in the air close to the cutting tool during the machining of S.C. Iron.

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APPENDIX

PROPOSED METHOD FOR THE DETERMINATION OF SMALL AMOUNTS
OF PHOSPHINE IN AIR

Using the equipment illustrated in Figs. 1(a) and 1(b) (or by similar means) slowly pass the air at a rate of 20 l./hr through three Drechsel bottles packed with glass beads and each containing 50 ml N/10 of potassium permanganate solution and 5 ml of sulphuric acid (5 per cent v/v). The air, which can be locally sampled by means of a funnel or glass tube fitted to an extension probe, is passed through a tightly packed plug of ignited asbestos to remove dust.

After a known volume of air has been sampled (usually 20 l) switch off the pump and disconnect the absorption vessels. The phosphate content of each absorber is determined individually in order to assess the efficiency of absorption; appreciable quantities of phosphate in the third vessel indicate possible losses of phosphine.

Empty the contents of the Drechsel bottles into 400 ml beakers, washing out the final traces with water and remove the beads by filtration. Add about 47–48 ml of N/10 oxalic acid solution, heat to 70 °C and carefully titrate the excess permanganate with oxalic acid until the colour is just discharged. Boil to reduce the volume to about 90 ml, cool and transfer to a 100 ml volumetric flask and dilute to volume.

Transfer a 25 ml aliquot to a 50 ml volumetric flask, add 2 ml of conc. hydrochloric acid, dilute to approx. 35 ml and mix well. Add 5 ml of ammonium molybdate (2 per cent), mix again and after carefully adding exactly 0.3 ml of stannous chloride solution (0.5 per cent) (Note 1) dilute to the mark and mix.

After standing 5 min, measure the optical density of the solution against water by means of a Spekker absorptiometer fitted with a mercury vapour lamp using Ilford 608 filters and 1 cm cells. Carry out a blank determination alongside the actual determination using the same permanganate solution and reagents. The phosphate content is obtained by referring to a calibration graph prepared as below.

$$P \times 1.098 \equiv PH_3$$

Note 1—The stannous chloride solution is prepared by dissolving 5 g $SnCl_2 \cdot 2H_2O$ in 5 ml of conc. hydrochloric acid and diluting to 100 ml. This solution keeps for about a week. The working solution is prepared by a tenfold dilution of this stock and should be freshly prepared.

Note 2—The above method is suitable for phosphine concentrations ranging from 0.001 to 0.012 mg/l. This range could no doubt be extended by modifications such as volume of air sampled, aliquot of absorbent taken or size of absorptiometer cell used with corresponding modification(s) in the calibration.

Calibration

Standard phosphorus solution—Dissolve 0.5036 g $NaH_2PO_4 \cdot 2H_2O$ in water and dilute to 1 l.

Dilute 25 ml of this solution to 500 ml

1 ml \equiv 0.005 mg P

Measure 125 ml of N/10 potassium permanganate solution and 12.5 ml sulphuric

acid (5 per cent v/v) into a 600 ml beaker and add 100 ml of approximately N/10 oxalic acid solution. Heat to 70 °C and titrate with the oxalic acid solution until the permanganate colour is just discharged. Evaporate by boiling gently, cool and dilute to 250 ml in a graduated flask.

Pipette 25 ml aliquots of this solution into six 50 ml flasks and add respectively 0, 2.0, 4.0, 6.0, 8.0 and 10.0 ml of the standard phosphorus solution. Add 2 ml of conc. hydrochloric acid and develop the molybdenum blue colour according to the instructions given in the method. Measure the optical density of the solutions against water and after correcting for the blank prepare a calibration graph relating optical density to amount of phosphorus present.

ALTERATIONS IN TISSUES FOLLOWING CARBON TETRACHLORIDE POISONING

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Abstract— CCl_4 administered into the duodenum by direct injection is absorbed rapidly and excreted chiefly through the lungs. High concentrations of CCl_4 are reached rapidly in adipose tissue and liver, with the concentration in the latter being about one quarter that of the adipose tissue.

The first observed biochemical alteration is a decrease in liver glycogen with a rise in blood sugar. An increase in liver neutral fat is noted in four hours, along with an increase in serum glutamic pyruvic transaminase and serum isocitric dehydrogenase. No change in serum glucose-6-phosphate dehydrogenase is noted.

A progressive decrease in the QO_2 of liver slices is noted reaching a minimum at 16 hr after administration of CCl_4 , then increasing again. The significance of early changes in liver contributing to the development of fatty liver is discussed.

THE wide application of carbon tetrachloride presents a greater hygienic problem than is commonly realized (VON OETTINGEN, 1955). Carbon tetrachloride has been shown to produce centrilobular necrosis and fatty degeneration of the liver (DRILL, 1958). The first histological changes noted are infiltration by polymorphonuclear leucocytes (WAHI *et al.*, 1955), followed by congestion and cloudy swelling. These changes may be observed within 6 hr of the administration of CCl_4 . On this basis it has been suggested that the swelling of the parenchymal cells narrows the sinusoids, with consequent decrease in the blood supply (DRILL, 1958). In contrast, STONER (1956) has reported a fall in temperature of the liver but no decrease in blood flow, suggesting the primary defect involves the metabolic activity of the liver directly.

Several interesting theories have been advanced recently to explain the action of CCl_4 in causing hepatocellular damage. As a result of biochemical studies, CHRISTIE and JUDAH (1954) and DIANZANI (1954) have suggested that administration of CCl_4 leads to mitochondrial changes resulting in a leakage of necessary enzymes or coenzymes with a consequent failure of the oxidative mechanism of the cell. On the other hand, BRODY (1959) has shown that there is a marked decrease in the catecholamine content of the adrenal gland following CCl_4 damage and that this can be prevented by administration of adrenolytic agents along with the CCl_4 . However, the mitochondrial changes and alteration in the catecholamine content do not occur until at least 15 and often 20 hr after the administration of the poison. Thus, there

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is a considerable delay between the time of onset of pathological changes and that of the observed biochemical alterations.

RECKNAGEL and ANTHONY (1959) have reported that fatty infiltration of the liver occurs as soon as 4 hr after administration of the toxin. In addition, RECKNAGEL and ANTHONY (1959) and NEUBERT and MAIBAUER (1959) have observed that the mitochondrial changes are not consistently found in the liver of animals that have sustained hepatocellular damage. Therefore an investigation was undertaken to ascertain when the early changes in the chemistry of the tissues following administration of CCl_4 occur. It was hoped that this study would provide a clue to a prime biochemical event which could explain subsequent pathological and biochemical changes. While this work was in progress, RECKNAGEL and LITTERIA (1960) reported that the level of CCl_4 reaches a peak in the liver in the first 2 hr, while the lipid content starts to increase 4 hr after administration of the poison. The work to be presented in this communication confirms the observations of RECKNAGEL and LITTERIA (1960) and describes a number of additional biochemical changes.

METHODS

Mode of administration of CCl_4

The oral administration of CCl_4 by stomach tube has the disadvantage of necessitating the use of a carrier, e.g. coconut oil, to dissolve the small volume of CCl_4 required to produce toxicity. However, the carrier by itself may produce effects mimicking some of the changes seen with CCl_4 (FRUNDER *et al.*, 1957). Therefore the CCl_4 was administered through the intestinal tract by direct injection into the duodenum.

Albino rats weighing 200 to 250 g were anesthetized with nembutal and a $\frac{1}{2}$ to $\frac{3}{4}$ in. incision made in the anterior abdominal wall. The first stage of duodenum was mobilized by pulling on the lesser omentum and the CCl_4 in a dosage of 0.1 ml/100 g body weight was injected directly into the duodenum using a 27 needle. Sham operated animals, in which a similar quantity of water was injected into the duodenum, served as controls. No operative or post-operative mortality occurred in either the control (sham-operated) or experimental animals, providing the CCl_4 -injected animals were allowed to feed *ad libitum* up to the time of operation. However, a mortality rate of 25–50 per cent was noted when fasted animals were used. Thus fed animals were used in all experiments. Except in cases where serial biopsies of the liver were taken, the animals were allowed to recover from the anesthetic and then returned to their cages. Animals that were not sacrificed in the first 12 hr were permitted to feed *ad libitum*. Water was provided to all the animals.

The CCl_4 content of the expired air was estimated by housing the experimental animal in a desiccator, the air from which was slowly passed through toluene by suction. A series of tests established that 95 per cent of a test quantity of CCl_4 placed in the desiccator was recovered by this method.

The determination of CCl_4

A red colour develops when chlorinated hydrocarbons are heated in alkaline pyridine (Fujiwara reaction). The intensity of the colour can be increased by the addition of acetone as suggested by HABGOOD and POWELL (1945).

(a) *Tissue extraction.* In the analysis of solid tissue a weighed sample of material was homogenized in a "Virtis" homogenizer in 5.0 ml toluene in the cold for a period of 30 to 60 sec. The homogenate was centrifuged and an aliquot of the toluene supernatant withdrawn and placed in a round-bottom standard-taper flask. In the analysis of blood a measured volume was transferred directly to the flask. The toluene extract or blood was then steam-distilled into a tube containing 1 ml of toluene, as recommended by HABGOOD and POWELL (1945). Approximately 30 ml distillate was collected.

(b) *Colour development.* A measured sample of the distillate, containing 20 to 120 μg CCl_4 , was added to the test tube. The following reagents were introduced in sequence into a test tube calibrated at 12.5 ml : 5.0 ml 20 % NaOH, 5.0 ml redistilled pyridine, and 0.5 ml acetone. The contents were shaken after each addition. The toluene content of the tube was made up to 1 ml if a sample smaller than this was taken from the distillate for estimation. The tubes were placed in a water bath at 90 °C for 10 min, cooled in an ice bath, and the volume made up to 12.5 ml with ethanol. The ethanol prevents cloudiness in the coloured upper phase. The upper phase was then decanted into a cuvette and the optical density measured at 535 $\text{m}\mu$ with a Coleman Junior Spectrophotometer.

A standard solution containing 200 μg of CCl_4 per ml toluene was prepared. To prepare a standard curve, varying amounts of the standard solution were introduced to round-bottom flasks and steam-distilled into 1 ml of toluene. The final amount of toluene was adjusted to 5 ml in all cases, and 1 ml aliquots of the distillate were used to obtain a standard curve. A typical standard curve is shown in Fig. 1. A similar curve was obtained when the colour was developed directly and the steam-distillation was omitted.

(c) *Recovery of CCl_4 .* Aliquots of the standard CCl_4 solution were added to the toluene in which various tissues were homogenized and the entire procedure carried

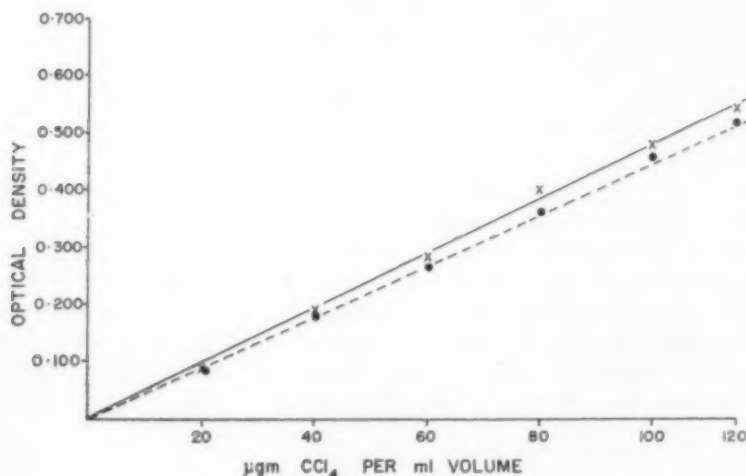


FIG. 1. Standard curves for CCl_4 determination.

x ————— x Steam distilled.
• - - - - - • Colour developed directly.

out as described above. Recoveries range between 95 and 105 per cent of the added CCl_4 , as is indicated in Table I. Thus extraction of tissues with toluene obviates the necessity of making corrections for the incomplete recovery of CCl_4 , as required in

TABLE I. RECOVERY OF CCl_4 FROM TISSUES

Tissue	$\mu\text{g CCl}_4$ added	$\mu\text{g CCl}_4$ found	per cent recovery
Liver	0	10	—
	600	643	105
	1000	992	99
Adipose tissue ..	0	20	—
	600	630	101
	1000	982	96
Kidney	0	0	—
	400	420	105

the procedure of RECKNAGEL and LITTERIA (1960). Furthermore the close agreement between the standard curves obtained with and without steam-distillation indicates that all of the CCl_4 added to the distillation-flask is recovered in the distillate.

Other analyses

Samples of liver to be analyzed for lipid content were homogenized in a 2 : 1 chloroform-methanol solution in an ice bath. The extract was then purified according to the method of FOLCH, *et al.* (1957). The cholesterol content was determined by the Liebermann-Burchard reaction (PUJAN and WALTER, 1937) and the lipid phosphorus by a modification of the method of YOUNGBURG and YOUNGBURG (1930). Neutral fats were determined according to the hydroxylamine hydrochloride procedure of RAPPORT and ALONZO (1955).

Glycogen was isolated by precipitation with alcohol following digestion of the tissue in hot 30 per cent potassium hydroxide, and estimated colorimetrically with the anthrone reagent. (UMBREIT *et al.*, 1957.) Glucose was determined according to the method of NELSON (1944) and lactate by the procedure of BARKER and SUMMERSON (1941).

Serum isocitric and glucose-6-phosphate dehydrogenases were determined by measuring the extent of the reduction of triphosphopyridine nucleotide (TPN) at 340m μ with a Beckman DU Spectrophotometer. In the case of the latter enzyme the TPNH formed may represent a summation of the glucose-6-phosphate dehydrogenase and the 6-phosphogluconic dehydrogenase activities. The serum glutamic-pyruvic transaminase was determined by following the oxidation of reduced diphosphopyridine nucleotide (DPNH) in the presence of lactic dehydrogenase by the pyruvate formed from the deamination of the added alanine.

RESULTS

A. Carbon tetrachloride content of expired air and tissues

The elimination of CCl_4 in the expired air collected from three animals following administration of CCl_4 is shown in Fig. 2. It is evident there was a very rapid

elimination of CCl_4 by this route. Usually from 70 to 75 per cent of the administered CCl_4 was excreted over a 36-hr period. This rate of excretion is of the same order as that noted by McCOLLISTER *et al.* (1951) in the monkey after the administration of C^{14} -labelled CCl_4 by inhalation over a period of 4 hr.

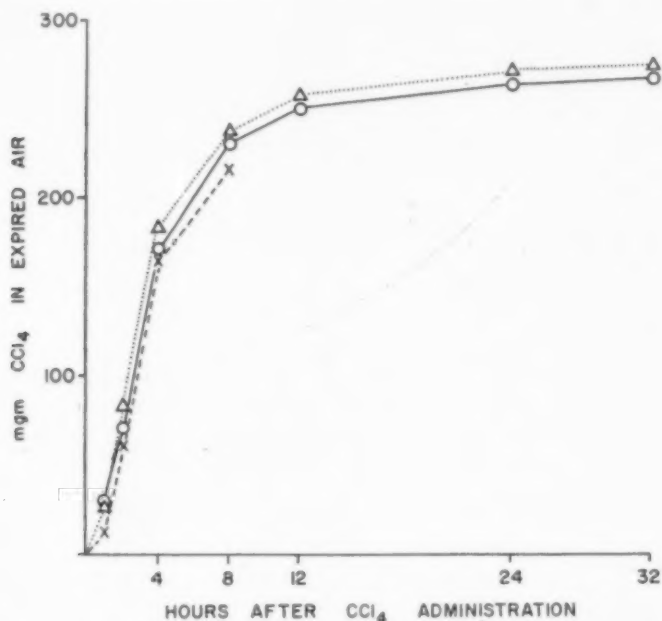


FIG. 2. Total CCl_4 in expired air of poisoned animals. Each curve represents a different animal.

The CCl_4 content of liver, adipose tissue, kidney and the blood of the rat after administration of this agent also was determined. Fig. 3 illustrates the level of CCl_4 in the liver over a 24-hr period. Each point on the graph represents the value from a separate animal. A maximum concentration was reached by the end of the first hour and this level was maintained until the beginning of the fourth hour, followed by a sharp drop resulting in a relatively insignificant level of CCl_4 by 24 hr. However, considerable variation among different animals at any one time interval was noted. Fig. 4 indicated the level of CCl_4 in the adipose tissue of the animal. In these experiments epididymal fat pads of the rat were used as the specimens of adipose tissue. The concentration of CCl_4 in the adipose tissue was found to be from 5 to 10 times as great as that in the liver. This is not unexpected as CCl_4 is a fat-soluble substance, and agrees with the observations of McCOLLISTER *et al.* (1951) who noted that the ratio of C^{14} in adipose tissue to that in the liver after administering C^{14} - CCl_4 was approximately 4 : 1. The level of CCl_4 in the adipose tissue remained high for a period of 8 hr, then fell slowly, but was still significant after 24 hr. The CCl_4 levels of the kidneys and blood are indicated in Figs. 5 and 6, respectively. In the kidney it was noted that a peak level occurred within the first hour after administration of the agent, followed by a gradual decrease, virtually to zero in 24 hr. A similar picture

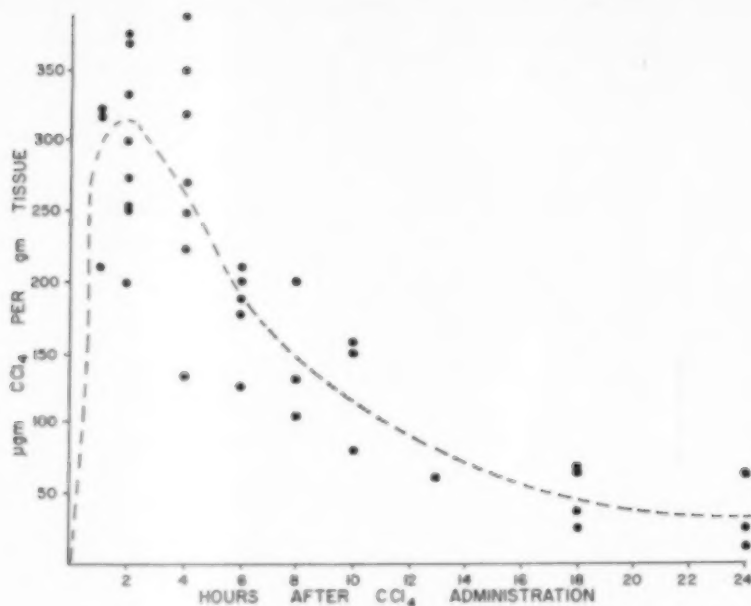


FIG. 3. CCl_4 content of liver. Each point represents a different animal.

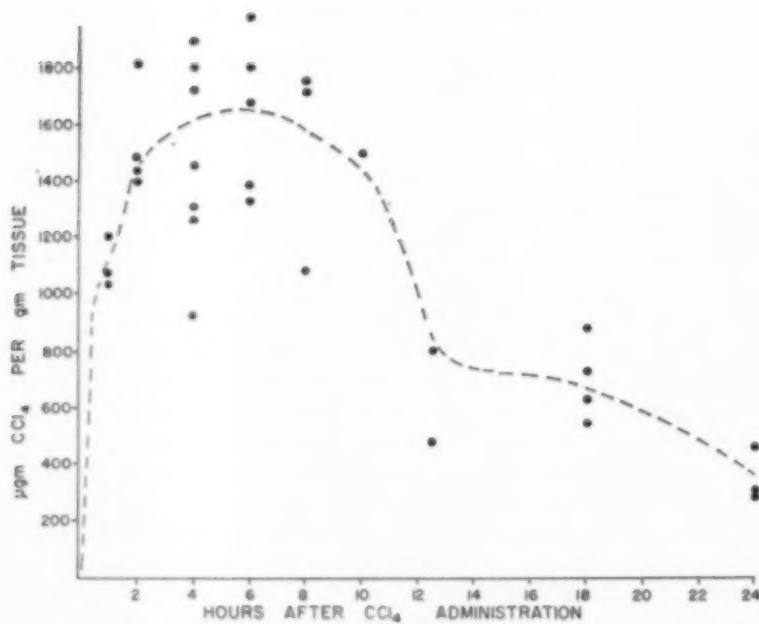


FIG. 4. CCl_4 content of adipose tissue. Each point represents a different animal.

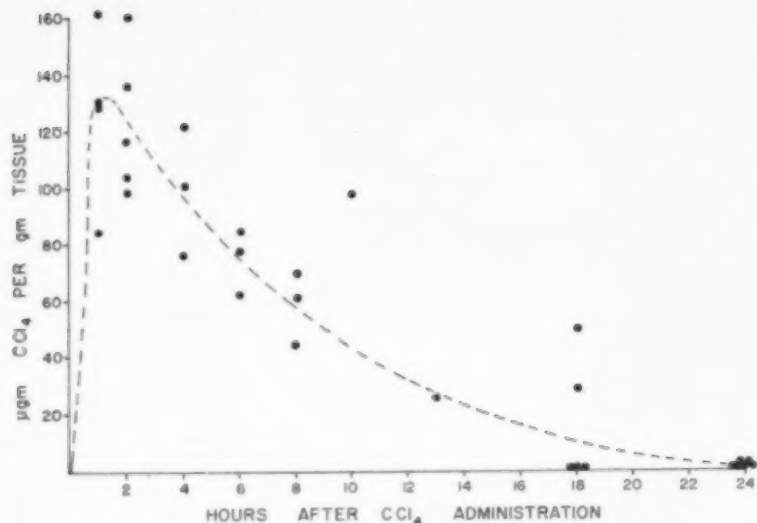


FIG. 5. CCl₄ content of kidney. Each point represents a different animal.

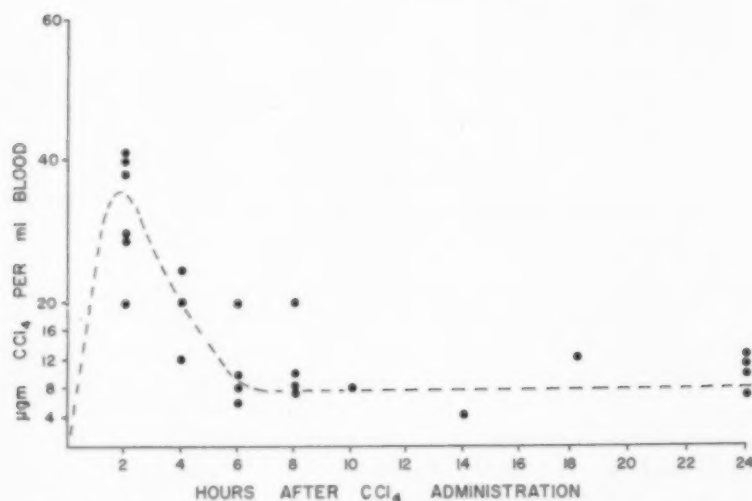


FIG. 6. CCl₄ concentration in blood. Each point represents a different animal.

is noted with blood except that a relatively low level was maintained even after lengthy periods. This is probably due to the continued release into the blood of the CCl₄ stored in the adipose tissue.

B. Alterations in components of liver and blood

The most frequently reported histological change following CCl₄ poisoning is fatty infiltration of the liver. The change in concentration of various fractions of the lipid of the liver was determined chemically by taking repeated liver biopsies at

two-hour intervals. A plot of the mean value from several animals is shown in Fig. 7. It will be noted that there is no significant difference in the levels of cholesterol and phospholipid between the control (sham-operated) and the experimental groups. On the other hand, a rise in the level of neutral fats occurred in the poisoned animals

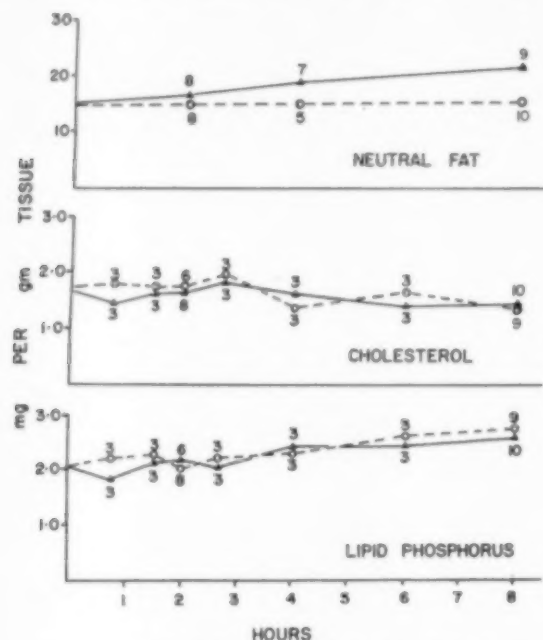


FIG. 7. Changes in lipid fractions in liver after CCl_4 administration.

Δ — experimental (CCl_4) animals
 ○ — controls

Each point represents the average of the indicated number of experiments. The value at zero time is the average of 18 determinations, for each fraction.

after the fourth hour, which is maintained or increased throughout the 8-hr period of the experiment.

A portion of each liver biopsy taken for lipid determinations was also analyzed for glycogen. The results presented in Fig. 8a show a fall in the level of liver glycogen during the first 2 hr in the poisoned animals. The drop continued until the glycogen was virtually exhausted. In the sham-operated animals on the other hand, the glycogen level remained unchanged during the first 2 hr, followed by an almost parallel drop to that shown by the experimental animals. The decrease in glycogen level in the control animals may be due to the fact that liver biopsies are taken while the animals are maintained under continuous anesthesia for periods of up to 8 hr. However, it is also possible that the decrease in liver glycogen is more rapid than normal in both groups of animals because the repeated biopsies represent recurring insults to the liver. To avoid these complications the experiment was repeated, but at intervals, instead of taking biopsies, the animals were sacrificed and the glycogen content of the liver estimated. The result of this experiment is shown in Fig. 8B.

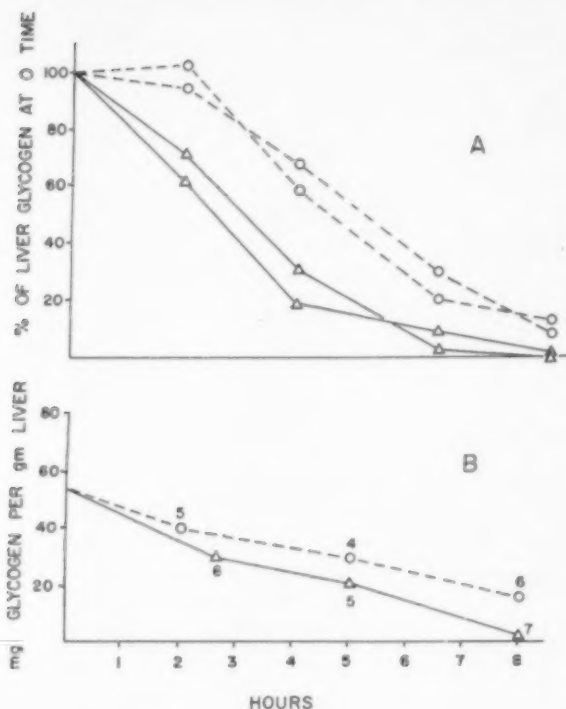


FIG. 8. Effect of CCl_4 administration on liver glycogen.

△ ————— △ experimental
○ ————— ○ controls

- A. Serial biopsies. Each line represents one animal.
B. One biopsy from each animal. Each point represents the average of the indicated number of experiments.

It is evident that a progressive decrease in liver glycogen still occurred in both groups of animals. However, the drop was more rapid in the CCl_4 -treated animals.

Two explanations for the fall in liver glycogen can be offered. Firstly, CCl_4 may induce a state of relative anoxia in the liver due to decrease in blood supply with consequent break-down of the glycogen to lactic acid. Secondly, the glycogen may simply be being broken down more rapidly to glucose which would appear in the blood stream, as would readily occur under the influence of epinephrine or glucagon. The first of these possibilities was investigated by determining levels of lactate in liver and blood. However, no significant difference in the level of lactate in liver or blood between the control and experimental animals was noted. The second possibility was investigated by estimating the blood sugar levels following the administration of CCl_4 . The results, shown in Fig. 9, are expressed as a percentage of the blood sugar found immediately post-operatively. It is evident that the blood sugar of the control animals falls progressively while the animal remains under the anesthetic. On the contrary, the level of blood sugar in the CCl_4 -poisoned animals rose. Thus a portion (about 20 per cent) of the decrease in liver glycogen could be explained by

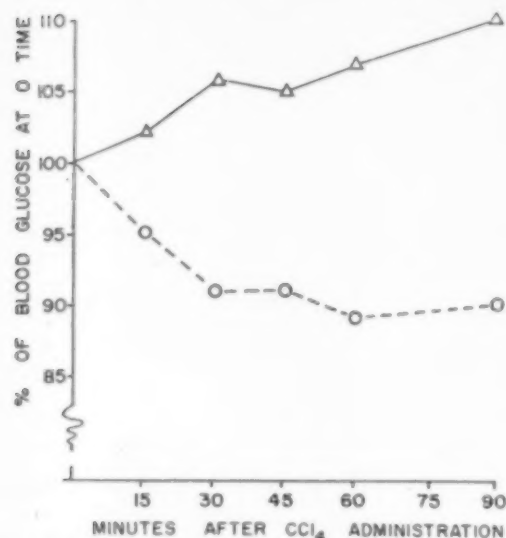


FIG. 9. Relative blood glucose level after CCl₄ intoxication.

△ ———— △ experimental
○ ———— ○ controls
Each point is average of six determinations.

the maintenance or increase in the blood sugar of the experimental animals in contrast to the fall in blood sugar in the control animals.

The QO_2 of liver slices taken from control and CCl₄-treated rats over a 48-hr period was studied. It is evident from Fig. 10 that the QO_2 decreases after administration of CCl₄ and reaches a minimum in 16 hr. Thereafter QO_2 began to rise and by the 48th hour exceeded the original value of 7.0. These changes in the QO_2 correspond to the mitochondrial damage noted by CHRISTIE and JUDAH (1954) at 15–20 hr after administration of CCl₄.

C. Alteration in serum enzyme levels

Alteration in the level of a specific enzyme or group of enzymes in serum often

TABLE 2. SERUM ENZYME LEVELS AFTER CCl₄ INTOXICATION μ M PYRIDINE NUCLEOTIDE OXIDIZED OR REDUCED PER ml SERUM

Hours after CCl ₄ administration	Glutamic pyruvic transaminase	Isocitric dehydrogenase	Glucose-6-phosphate dehydrogenase
0	0.102 (5)*	0.002 (13)	0.331 (4)
4	0.259 (3)	0.000 (5)	—
8	0.771 (4)	0.035 (4)	0.293 (2)
16	1.015 (4)	0.221 (6)	—
24	0.770 (1)	—	0.347 (1)
48	1.949 (4)	0.158 (4)	0.260 (2)

* Number of animals.

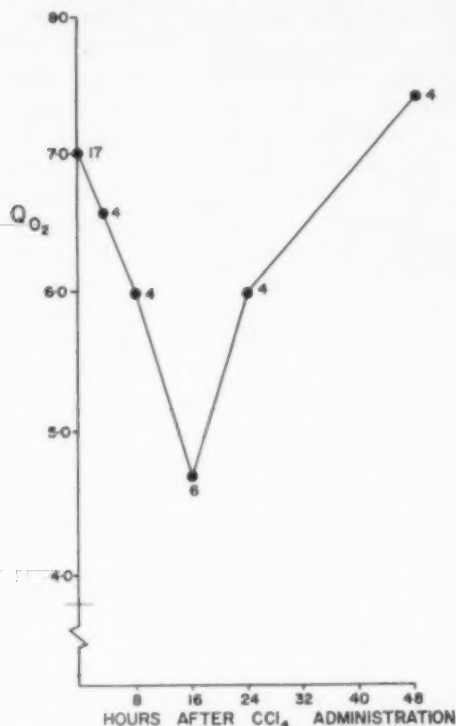


FIG. 10. Q_{O_2} of liver slices following CCl_4 intoxication. Each point represents the average of the indicated number of experiments.

occurs in pathological conditions. An attempt was therefore made to determine if increases in serum enzyme levels occurred immediately following CCl_4 poisoning. Isocitric dehydrogenase, glucose-6-phosphate dehydrogenase and glutamic-pyruvic transaminase were selected. The results are indicated in Table 2. It will be noted that the activity of the serum glutamic-pyruvic transaminase is doubled in 4 hr, but a considerable variation was noted among individual animals in the same group. Eight hours after administration there was a consistently great increase in activity. No serum isocitric dehydrogenase could be detected for 8 hr. A steady increase with activity of the enzymes was then noted only in the experimental animals. On the other hand, the level of glucose-6-phosphate dehydrogenase showed no detectable change over the 48-hr period during which serum enzymes were assayed. Thus, the mere presence of isocitric dehydrogenase indicates a pathological condition of the liver in rats.

DISCUSSION

This communication presents evidence that a biochemical lesion in hepatocellular damage due to CCl_4 administration occurs before the fifteen-hour period required to produce mitochondrial change or depletion of adrenal catecholamines. Thus the concentration of CCl_4 in liver is maximal in 1 hr and remains at a high

level for about 4 hr before dropping sharply. In adipose tissue, the carbon tetrachloride reaches a peak concentration in 2 hr and begins to decline after 8 hr. The adipose tissue may provide a reservoir of CCl_4 which is slowly released into the blood stream. This explains the persistent but low level found in the blood.

The levels of CCl_4 in blood and liver are approximately 40 per cent of those obtained by RECKNAGEL and LITTERIA (1960). However, the dosage administered in our experiments was only 0.1 ml CCl_4 per 100 gm body weight instead of 0.25 ml. RECKNAGEL and LITTERIA (1960) report maximal concentration of CCl_4 in liver within 2 hr, while the experiments cited here show a diffuse peak over 4 hr. It is possible that the absorption of CCl_4 is facilitated by coconut oil, used by RECKNAGEL and LITTERIA (1960) as a carrier, thus increasing the concentration during the first hour. Nevertheless, the elevation of liver lipid accounted for entirely by triglycerides occurs in 4 hr.

Brody and Calvert (BRODY, 1959; BRODY and CALVERT, 1960; CALVERT and BRODY, 1960) have suggested that the administration of CCl_4 causes a discharge of adrenal catecholamines which in turn produces the mitochondrial damage and fatty accumulation in the liver. The evidence cited is the decrease of adrenal catecholamines 20 hr after CCl_4 poisoning. The biochemical defects may be partially relieved by adrenolytic agents, spinal section and adrenalectomy. WERTHEIMER (1948) has pointed out that fatty infiltration of the liver can be prevented by adrenalectomy, adrenolytic agents or section of the spinal cord above the level of T6, regardless of the lipotropic agent used, e.g. phosphorus, phloridzin, choline deficiency.

The rapid loss of liver glycogen accompanied by the maintenance of blood glucose level by the experimental animals, in contrast to the greatly decreased loss of glycogen with a decrease in blood glucose level by the control animals has been reported in this paper. This supports the suggestion that epinephrine is involved in initiating some of the lesions attributed to CCl_4 . However, excess epinephrine by itself for example, in patients with pheochromocytomas, does not induce fatty livers. It can be speculated that a preliminary stimulation of adrenal catecholamine occurs, leading to a depletion of liver glycogen. This would then render the parenchymal cells more susceptible to damage by direct action of CCl_4 . A high mortality was observed in our experiments after administration of CCl_4 to fasted animals which have a hepatic glycogen level of 5–10 per cent that of fed rats. This is consistent with the greater susceptibility of animals with glycogen-depleted livers to CCl_4 poisoning.

The changes noted in the level of adrenal catecholamines 20 hr after CCl_4 administration may be secondary to the massive hepatocellular damage occurring immediately following CCl_4 administration. The hypoglycemia noted (MINOT and CUTLER, 1930) one day after poisoning may also be due to the inability of the liver to maintain the blood sugar due to lack of readily available glycogen.

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THE THERMAL ENVIRONMENT OF SOME MODERN RAILWAY SIGNAL BOXES

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INTRODUCTION

DURING discussions with members of the British Railways Department of Operational Research concerning desirable thermal conditions for signalmen and the most suitable methods of heating new signal boxes, it became apparent that no records of thermal conditions in existing signal boxes were available. It was decided that useful information might be obtained if regular visits could be made to some modern signal boxes throughout the 1958-59 heating season for the purpose of assessing the thermal environment and comfort of the signalmen. Officials of British Railways were asked to select some signal boxes suitable for investigation. Five modern boxes were chosen and will be referred to subsequently as boxes A, B, C, D and E. Four of these were heated by means of hot water flowing at low pressure through radiators of conventional pattern. The fifth box (B) was heated by a unit containing a fan blowing air, heated to a set temperature controlled by a thermostat, into the box.

1. METHODS

The temperature of the air and its speed were respectively measured with mercury-in-glass thermometers and silvered kata-thermometers at heights of 5 ft 6 in. and 6 in. from the floor. The mean radiant temperature at a height of 5 ft 6 in. was ascertained from readings of a globe thermometer. The atmospheric humidity was measured with a whirling hygrometer which was also used to measure the temperature of the air at three or more places inside, and at one position outside, the signal box. Particular attention was paid to the difference between the temperatures of the air at head-level and at floor-level since all the boxes were heated by convective systems which are specially liable to produce considerable vertical gradients of temperature which are well-known causes of thermal discomfort.

The observer questioned the signalmen concerning their sensations of warmth and impressions of freshness when the temperatures were measured.

Observations were made three times a day in boxes A, B, and C. Boxes D and E were visited on the same day and observations were made twice in each box, once in the morning and once in the afternoon. Each box was visited once a fortnight during the period from mid-October 1958 to mid-March 1959.

Normally, signalmen work three eight-hourly shifts:

- (i) from 6 a.m. to 2 p.m.,

(ii) from 2 p.m. to 10 p.m., and

(iii) from 10 p.m. to 6 a.m., working for one week on each shift.

Therefore on most visits men on two shifts were encountered and all the staff were met on several occasions.

2. RESULTS

The average values of the environmental temperatures and air speeds measured in each box are given in Table I.

The relative humidity of the air in the boxes varied from 37 to 50 per cent. and, as variations of this order have little effect upon warmth at these temperatures, humidity may be omitted from further consideration.

TABLE I. THE AVERAGE VALUES OF t_a , t_g , AND t_m , THE AIR, GLOBE, AND MEAN RADIANT TEMPERATURES RESPECTIVELY EXPRESSED IN DEGREES FAHRENHEIT, WITH v , THE AIR SPEED EXPRESSED IN FEET PER MINUTE

Box	Distance from floor						Vertical gradient of air- temperature
	5 ft 6 in.				6 in.		
	ta	tg	tm	v	ta	v	
A	70.4	69.5	68.9	13	66.8	21	+ 3.6
B	70.4	68.6	67.7	9	64.4	12	+ 6.0
C	70.4	69.8	69.4	19	67.5	31	+ 2.9
D	74.1	72.6	71.7	14	69.3	14	+ 4.8
E	70.4	69.5	69.0	11	68.6	20	+ 1.8

The rates of air movement were low and similar to those measured in rooms with closed windows and no artificial ventilation. One would expect the environment of the signal boxes to feel slightly stuffy.

The temperatures of the globe thermometer were consistently lower than the air-temperatures but the differences were small and the greatest difference between the mean radiant temperature and the air temperature was only 2.7 °F. Thus the mean radiant temperature need not be considered further.

There was a striking agreement between the air-temperatures at head-level in all the boxes except box D. The differences between the air-temperature at head-level and floor level were small with the exception of that observed in box B which was 6 °F.

The results from each signal box will now be considered separately.

Box A

This box was approximately 22 ft wide and 16 ft long and it was heated by five radiators placed round the walls. Hot water was supplied to the radiators from a gas-fired boiler which had a thermostatic control. The thermostat could be set to give a maximum water-temperature of 190 °F. The front and sides of the box were glazed from a height of three feet upwards and there were large sliding windows as well as casement types.

The box was visited on ten different days during the winter and three sets of

observations were made on the occasion of each visit. Although the external air-temperature varied from 37 °F to 59 °F the average air-temperature inside the box was 70.4 °F, the range of temperatures being from 63 °F to 76 °F, but nearly three-quarters of the observations ranged from 68 °F to 74 °F. This shows that the heating system worked satisfactorily. The maximum gradient of air-temperature, that is, the amount by which the temperature of the air at head-level exceeds that at floor-level, was 6.7 °F but the average gradient was less than 4 °F. Subsequently this difference between the air-temperatures at head and floor levels will be called the vertical gradient of air-temperature.

No discomfort was experienced by the signalmen except on four occasions when some men were too cool. Since, in addition, they found the environment neither fresh nor stuffy one may conclude that satisfactory thermal conditions prevailed in the signal box during the day.

However, at night, the box was said to be uncomfortably cold and the discomfort was aggravated by strong winds. Windows were hardly ever opened and gaps around the window frames were stuffed with paper in order to eliminate draughts. The staff considered that conditions at night might have been improved by re-siting the radiators so that the recorder, a signalman who was unable to leave his desk except for very short periods during the working period, might receive enough heat to make him comfortably warm.

Box B

This box was about twenty feet square in plan and the front and sides were almost wholly glazed. The box was heated by hot air issuing from an aperture two feet square in the back wall at about head-level. Another aperture at floor-level permitted air to be drawn into the heating apparatus from the signal box. A thermostat was fixed to the wall near the air inlet and the action of the thermostat was to control the fan propelling hot air into the signal box. This heating arrangement produced marked vertical gradients of air-temperature. On one occasion the gradient rose to 12 °F but this was due to the use of a paraffin stove which had been used to raise the air-temperature to a comfortable level owing to the failure of the heating unit to do so in spite of running continuously during a spell of cold weather. Measurement of the air-temperature in this box was difficult because of rapid variations of temperature which occurred when the fan was switched on by the action of the thermostat. The temperature of the air could rise by 5 °F in as many minutes when the fan was operating. The temperature of the air issuing from the outlet of the heater varied from 100 °F to 110 °F.

The mean air-temperature in the box was 70.4 °F and the range was from 64 °F to 78 °F but over 50 per cent of the observations ranged from 69 °F to 76 °F.

On the whole it appeared that little actual thermal discomfort was experienced by the signalmen apart from the occasions when the paraffin stove had to be used but the men disliked the heating system because of the difficulties experienced in adjusting it so as to obtain comfortable indoor temperatures.

Box C

This signal box was similar to those already described as the front and sides were mostly glass. The box was heated by means of hot water flowing through pipes which were laid round the front and sides of the box underneath the windows. The

top of the pipes was covered by a wooden shelf forming a bench-type seat round the box and the vertical gap between the floor and the front of the shelf was filled in with a louvred metal strip. The water was heated by a gas-fired boiler under manual control.

This box was visited on nine days and twenty-six sets of observations were made. The average air-temperature was 70.4 °F and the range was from 64 °F to 82 °F but in 75 per cent of the observations the air-temperature ranged from 68 °F to 77 °F. The average vertical gradient of air-temperature was only 2.9 °F. Little thermal discomfort was experienced by the occupants.

Box D

This box was staffed by a larger number of men than in the three boxes previously described. There were seven men of whom three were signalmen, three were recorders while the seventh man was known as the "regulator". The "regulator" was in charge of the signal box and he relieved the signalmen in turn during meal breaks while at other times he sat with the recorders. The box was 50 ft wide and 15 ft long and heated by nine radiators placed round the walls.

The box was visited on nine different days and altogether nineteen sets of observations were made. The average air-temperature was the highest recorded in a signal box, viz., 74.1 °F and the air-temperature ranged from 71 °F to 78 °F. The average temperature of the air 6 in. above the floor was 69.3 °F so that the average vertical gradient of the air-temperature was 4.8 °F.

In spite of the relatively high temperatures, discomfort was experienced only on seven occasions when a few of the signalmen were too warm. However, the occupants commented on the stuffy nature of the environment and regretted that, owing to the pollution of the outside air with soot (most of which came from steam locomotives) they could not open the windows.

Box E

This box was normally staffed by two signalmen, two recorders and a "regulator". As in other boxes the front and two sides were mostly of glass with sliding and hinged windows. The box was heated by eight radiators arranged along the sides and back of the box. A thermostatically controlled gas-fired boiler supplied hot water to the radiators.

The average air-temperature at head-level was 70.4 °F and the range was from 67 °F to 74 °F but nearly 80 per cent of the observations ranged from 69 °F to 72 °F. The average air-temperature at floor-level was 68.6 °F so that the average vertical gradient of air-temperature was only 1.8 °F. The incidence of thermal discomfort amongst the occupants was negligible.

3. DISCUSSION

When the results were pooled, the overall incidence of thermal discomfort amongst the signalmen was only 5 per cent of some 379 assessments of warmth. The average air-temperature associated with thermal comfort was 71.2 °F with a comfort zone ranging from 69 °F to 73 °F. Since the signalmen could exercise control over the temperatures inside the signal boxes, it is reasonable to assume that an air-temperature of about 70 °F was the temperature of choice. This is some 5 °F

higher than the temperature preferred by the factory operatives investigated by BEDFORD (1936). It is, however, about the same temperature as that preferred by sedentary subjects studied by MUNRO and CHRENKO (1949). Since the modern signal box is electrically operated, little physical work is involved so that signalmen are virtually sedentary persons.

The results have shown that thermal conditions in the boxes were generally satisfactory but it must be remembered that the observations were made during the day. On many occasions signalmen remarked that their boxes were very cold at night.

It is reasonable to suppose that the various heating systems were all initially capable of maintaining comfortable indoor temperatures when the external temperature was say 32 °F but lack of efficient maintenance reduced the efficiency of the boilers, resulting in a lowered heat output, so that it was impossible to achieve comfortable conditions during very cold winter nights.

Evidence in support of this idea came from Box E where, in view of the statements made concerning conditions at night, an observer measured the air-temperature and assessed the thermal comfort of the occupants throughout one night shift. It was found that the internal air-temperature of the box remained steady at about 70 °F and thermal conditions were quite satisfactory, but the external temperature was well above 32 °F. The boiler was inspected and it was delivering its maximum output of heat, so that if the external temperature fell to 32 °F or below a temperature of 70 °F could not be maintained in the signal box. In this instance, the gas-burners were in a very poor condition.

Another possibility is that those responsible for the design of the heating systems might have designed them to maintain internal temperatures of 65 °F with an external temperature of 30 °F. If this was so, then, even if the apparatus were adequately serviced, comfortable indoor conditions could never be achieved during cold winter nights. This might have happened in Box B where the heater could not maintain comfortable conditions even during the day and another heater was used to raise the air-temperature to a comfortable level.

It is understood that this particular heater was the first of its kind to be installed in a signal box in this region of British Railways and that its method of operation was being modified in an attempt to improve its performance. This calls for further comments as we understand that the same type of heater may be used in other signal boxes.

The thermostat was supposed to maintain the internal air-temperature at a fixed level but it was not possible to ascertain what this was. The thermostat was placed alongside a coat rack and it was often covered with a heavy overcoat. On one occasion it was covered with a cloth. This cloth had originally been wet and the device was used to prevent the thermostat reaching the temperature at which it would switch off the fan blowing hot air into the box. In other words, the signalmen arranged matters so that the hot air was blown continuously into the box and comfortable conditions were obtained by men on the night shift. When the next shift came on duty at 6 a.m., they found the box unpleasantly hot and they would have opened the windows but for the close proximity of a gas works and a fish cannery.

The heating system in Box B cannot be considered as satisfactory because, in addition to difficulties in setting thermostats, comfortable conditions could not be

achieved during very cold days without an additional heater, internal air-temperatures were very unsteady, and vertical gradients of air-temperature tended to be uncomfortably high.

It is, of course, well-known that convective heating systems produce vertical gradients of air-temperature so that people tend to have uncomfortably cool feet and uncomfortably warm heads. Discomfort of this nature did not occur in this investigation in the boxes where the older fashioned heating systems were installed. Although these heaters are called "radiators" most of the heat is lost by convection, yet uncomfortable gradients of temperature did not occur.

When one considers the design of a heating system in a signal box it is desirable to provide not only a comfortably warm environment for the signalmen but also to ensure that no enervating impressions of stuffiness are evoked, since the signalmen should remain mentally alert throughout the working spell. In other words, the environment should feel fresh as well as warm. For air to seem fresh, the head of the occupant must feel pleasantly cool and this is unlikely to happen if the air-temperature at head-level exceeds 70 °F especially when the rate of air movement at head-level is very low. The easiest and cheapest method of increasing the rate of air movement at head-level is to open the windows, but when the air is so dirty as in the case of Box D, or when the air stinks as in Box B, the occupants are naturally not keen to open windows. In Box C small circular louvred ventilators had been inserted in some of the windows as signalmen had previously mentioned that very large windows did not provide convenient means of ventilation. The signalmen also pointed out that absence of auxiliary heaters necessitated their wearing overcoats during the night shift when recorders found it difficult to hold their pens properly owing to the cold.

In conclusion, we think that very serious consideration should be given to radiant heating systems in general and to floor-heating systems in particular, and whatever heating system is used the designer should bear in mind that signalmen require higher air-temperatures than factory operatives and thus avoid conducting rather expensive experiments with heating systems such as occurred in Box B.

4. SUMMARY

- (a) Signalmen in modern boxes prefer air-temperatures some 6 °F higher than factory operatives, i.e. 71 °F when convective heating systems are used.
- (b) Convective heating systems in signal boxes may, if operated efficiently, provide comfortable warmth in winter but they tend to produce stuffy conditions.
- (c) When new signal boxes are designed, very serious consideration should be given to radiant heating systems and especially floor heating.

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A SEARCH FOR SIMPLE COMBINATIONS OF F.E.V. (1 second) AND F.V.C. INDEPENDENT OF AGE AND PHYSIQUE IN COALMINERS

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Abstract—Measurements of Forced Expiratory Volume, 1 second (F.E.V.) and Forced Vital Capacity (F.V.C.) were made on about 850 men representing a population of working coalminers in a colliery in Scotland. The results were sub-divided into four groups corresponding to men with and without radiological pneumoconiosis and with and without respiratory symptoms, the latter condition being defined in terms of replies to a questionnaire. Account was also taken of age and sitting height.

F.E.V. (1 sec) and F.V.C. were both found to decrease with age, the former rather more rapidly than had been reported by other investigators for "normal" men. Both measurements increased with sitting height. Respiratory symptoms were associated with a lowering of both measurements, whereas radiological pneumoconiosis had no marked effect.

Combinations of F.E.V. (1 sec) and F.V.C. were investigated in the hope of finding an index of ventilatory function independent of age and sitting height in this population, corresponding to the "Tiffeneau Ratio" (or F.E.V. per cent) reported by other workers for normal men in non-mining populations.

F.E.V. per cent tended to decrease with age amongst all the men examined. This ratio was found to be independent of sitting height in the group consisting of men without pneumoconiosis and without respiratory symptoms, but in the other three groups tended to increase with sitting height.

No linear combination of F.E.V. (1 sec) and F.V.C. was independent of age and sitting height in this population. The combination least well correlated with age and height was $[F.V.C. - F.E.V. (1 \text{ sec})]$, i.e., that part of the forced vital capacity expelled after the first second. No linear combination of the logarithms of F.E.V. (1 sec) and F.V.C. was independent of age and sitting height, the least well correlated being the function $[\log F.V.C. - 0.8 \log F.E.V. (1 \text{ sec})]$.

1. INTRODUCTION

FOR the purpose of assessing ventilatory function in the men under examination as part of the National Coal Board's Pneumoconiosis Field Research (FAY, J. W. J. 1957, FAY, J. W. J., 1959) the Forced Expiratory Volume, 1 sec (F.E.V.) test is applied as the basic measurement. This test is relatively simple to carry out in the field, and has been shown to be repeatable (ASHFORD, J. R., *et al.*, 1960). The F.E.V. (1 sec) measurement is made using the apparatus described by GAENSLER as modified by Carpenter and others (CARPENTER, R. G. *et al.*, 1956), and at the same time the Forced Vital Capacity (F.V.C.) is also recorded.

The use of either of these measurements alone to describe ventilatory function is, however, subject to the disadvantage that the value is dependent upon various other factors, particularly age and physique. Thus, the use of F.E.V. (1 sec), for example, in any study of the inter-relationships between dust exposure, pneumoconiosis category and ventilatory function means that account must be taken of

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these physical factors. Obviously a simple "index" of ventilatory functional efficiency, independent of age and physique, would be invaluable, and many attempts have been made to derive such an index.

An example is MOTLEY's "Ventilation Factor", which was calculated by taking the average of the predicted values of the three-second vital capacity, the maximal breathing capacity and the residual volume as a percentage of the total lung volume. The most commonly used combination of measurements of ventilatory function is, however, the ratio of F.E.V. (1 sec) and F.V.C. For example, TIFFENEAU and his co-workers found that if the F.E.V. (1 sec), which they termed the "Capacité pulmonaire utilisable à l'effort" (C.P.U.E.), was expressed as a direct percentage of the vital capacity, the resulting figure (representing the proportion of a maximum expiration expelled in the first second) was fairly constant in their "normal" subjects, with an average value of 83.8 per cent. Much further work has been carried out on this ratio, which has been variously known as the "Tiffeneau Ratio", the Forced Expiratory Ratio (F.E.R.) and the F.E.V. per cent. Some investigators have confirmed the conclusions of Tiffeneau and his colleagues, finding that the F.E.V. per cent has a value of about 80 per cent for normal subjects and is independent of various factors, such as age, physique, ambient temperature, and barometric pressure (GAENSLER, CAPEL, PEMBERTON and MILLER). In a later study, however, MILLER *et al.* found a tendency for the ratio to decrease with age. The effect of smoking habits has also been investigated and found to have no significant effect on the ratio. These conclusions are based on the study of "normal" subjects, but it has been shown that F.E.V. per cent is greatly affected by certain physical conditions in hospital patients. Thus, GILSON pointed out that obstructive conditions in the respiratory tract may cause a reduction of the ratio to 50 per cent or less, compared with the normal value between 70 per cent and 90 per cent. CAPEL and SMART found that the ratio fell notably in patients with obstructive airway disease, although there was little reduction with loss of effort tolerance in patients with heart disease.

From the point of view of the Pneumoconiosis Field Research it was therefore of considerable interest to determine to what extent the conclusions about F.E.V. (1 sec) and F.V.C. based on studies of normal subjects and hospital patients could be applied to coalminers, whose lung function might have been impaired by exposure to airborne dust. The purpose of this paper is to examine the relationships, in a population of working coalminers, between combinations of F.E.V. (1 sec) and F.V.C. on the one hand, and age and sitting height on the other, account being taken of the effect of radiological pneumoconiosis and respiratory symptoms. Sitting height was chosen as the measure of physique, because it was better correlated with F.E.V. (1 sec) and F.V.C. than any other single anthropometric measurement made in the research.

2. METHODS

The population examined comprised underground and surface workers at a colliery in Scotland. In all, 852 men were included, representing about 95 per cent of the complete population. Each man was asked a series of questions about respiratory symptoms and a diagnosis of "with symptoms" or "without symptoms" was made. (See Appendix 1.) Age, weight, standing height and sitting height were recorded, and four measurements of F.E.V. (1 sec) and F.V.C. were taken. The readings based on

the first expiration were discarded to obviate error due to "learning effect" (ASHFORD, J. R., *et al.*, 1960), and the figures used in the analysis are based on the average of the measurements made on the second, third and fourth expirations. A 14 in \times 14 in P.A. chest X-ray was taken of each subject and the films were read by two very experienced observers in terms of the (1950) I.L.O. classification for radiological pneumoconiosis.

On the basis of the X-ray readings and the respiratory symptoms questionnaire, the population was divided into four sub-groups:

- (i) Category 0 pneumoconiosis, without respiratory symptoms.
- (ii) Category 0 pneumoconiosis, with respiratory symptoms.
- (iii) Category 1 or more pneumoconiosis, without respiratory symptoms.
- (iv) Category 1 or more pneumoconiosis, with respiratory symptoms.

In view of the comparatively small number of men with the higher categories of pneumoconiosis it was not considered worthwhile to break down the results for men with category 1 or more pneumoconiosis in terms of the separate categories.

It should be borne in mind that many of the men classed as category 0 have a record of considerable exposure to airborne dust. Although their X-ray films do not show a sufficient degree of abnormality to qualify for category 1 or more pneumoconiosis, it is possible that their respiratory function has been modified by the retention of dust in the lungs.

3. RESULTS

Prevalence of pneumoconiosis and respiratory symptoms

The prevalence of pneumoconiosis and respiratory symptoms in terms of age is summarized in Table 1, which shows that both conditions are almost completely absent in men of less than 40 years of age. Amongst the older men, however, there is a marked tendency for the prevalences to increase with increasing age. In all about 14 per cent of the colliery population have category 1 or more pneumoconiosis and about 16 per cent have respiratory symptoms.

The distribution of the population in terms of sitting height is given in Table 2. There is no marked association between sitting height and either radiological pneumoconiosis or respiratory symptoms.

F.E.V. (1 sec), F.V.C. and F.E.V. per cent in terms of age

The relation between F.E.V. (1 sec) and age is illustrated in Table 3. There is a marked decrease in F.E.V. (1 sec) with increasing age. For the men without radiological pneumoconiosis or respiratory symptoms the average F.E.V. (1 sec) falls from about 4.0 l. for the under 30 years age groups to about 2.5 l. for the over 60 years age group. The average F.E.V. (1 sec) of the men with respiratory symptoms is of the order of 0.5 l. lower than that of the men of the same age without symptoms. When the effect of symptoms is taken into account there is no systematic difference between the average F.E.V. (1 sec) of those men with and those without radiological pneumoconiosis.

It is interesting to note that in their studies of 77 normal male subjects, MILLER *et al.* observed a decrease in average F.E.V. (1 sec) from 4.15 l. for the 20-29 years age group to 3.21 l. for the 50-59 years age group. In this colliery population the rate

TABLE 1. PREVALENCE OF RADIOLOGICAL PNEUMOCONIOSIS AND RESPIRATORY SYMPTOMS IN TERMS OF AGE

Radiological Pneumoconiosis	Age group	Category 0						Category 1 or more						All					
		Without			With			Without			With			Without			With		
		No.	%		No.	%		No.	%		No.	%		No.	%		No.	%	
Respiratory symptoms																			
Under 21	159	97.5	4	2.5	163	100.0	0	0.0	0	0.0	0	0.0	159	97.5	4	2.5	163	100
21-30	153	97.5	4	2.5	157	100.0	0	0.0	0	0.0	0	0.0	153	97.5	4	2.5	157	100
31-40	130	94.2	3	2.2	133	96.4	5	3.6	0	0.0	5	3.6	135	97.8	3	2.2	138	100
41-50	112	68.7	30	18.4	142	87.1	15	9.2	6	3.7	21	12.9	127	77.9	36	22.1	163	100
51-60	82	46.9	31	17.7	113	64.6	34	19.4	28	16.0	62	35.4	116	66.3	59	33.7	175	100
Over 60	13	23.2	10	17.9	23	41.1	13	23.2	20	35.7	33	58.9	26	46.4	30	53.6	56	100
All	649	76.2	82	9.6	731	85.8	67	7.9	54	6.3	121	14.2	716	84.0	136	16.0	852	100

TABLE 2. PREVALENCE OF RADIOLOGICAL PNEUMOCONIOSIS AND RESPIRATORY SYMPTOMS IN TERMS OF SITTING HEIGHT (CMS).

Radiological Pneumoconiosis	Category 0						Category 1 or more						All					
	Without			With			Without			With			Without			With		
	No.	%	No.	No.	%	%	No.	%	No.	No.	%	%	No.	%	No.	No.	%	%
78-79	1	50.0	1	50.0	2	100.0	0	0.0	0	0.0	0	0.0	1	50.0	1	50.0	2	100
80-81	5	100.0	0	0.0	5	100.0	0	0.0	0	0.0	0	0.0	5	100.0	0	0.0	5	100
82-83	16	66.7	3	12.5	19	79.2	3	12.5	2	8.3	5	20.8	19	79.2	5	20.8	24	100
84-85	51	70.8	9	12.5	60	83.3	6	8.3	6	8.3	12	16.7	57	79.2	15	20.8	72	100
86-87	89	71.8	14	11.3	103	83.1	12	9.7	9	7.3	21	16.9	101	81.5	23	18.5	124	100
88-89	145	79.2	12	6.6	157	85.8	14	7.7	12	6.6	26	14.2	159	86.9	24	13.1	183	100
90-91	148	74.0	21	10.5	169	84.5	16	8.0	15	7.5	31	15.5	164	82.0	36	18.0	200	100
92-93	109	79.0	16	11.6	125	90.6	10	7.2	3	2.2	13	9.4	119	86.2	19	13.8	138	100
94-95	58	81.7	5	7.0	63	88.7	4	5.6	4	5.6	8	11.3	62	87.3	9	12.7	71	100
96-97	17	85.0	0	0.0	17	85.0	1	5.0	2	10.0	3	15.0	18	90.0	2	10.0	20	100
98-99	5	62.5	1	12.5	6	75.0	1	12.5	1	12.5	2	25.0	6	75.0	2	25.0	8	100
100-101 ..	4	100.0	0	0.0	4	100.0	0	0.0	0	0.0	0	0.0	4	100.0	0	0.0	4	100
102-103 ..	1	100.0	0	0.0	1	100.0	0	0.0	0	0.0	0	0.0	1	100.0	0	0.0	1	100
All	649	76.2	82	9.6	731	85.8	67	7.9	54	6.3	121	14.2	716	84.0	136	16.0	852	100

Sitting Height (cms).

TABLE 3. AVERAGE F.E.V. 1 SEC (LITRES) IN TERMS OF RADIOLOGICAL PNEUMOCONIOSIS, RESPIRATORY SYMPTOMS AND AGE

Radiological pneumoconiosis		Category 0			Category 1 or more			All		
Respiratory symptoms		With-out	With	All	With-out	With	All	With-out	With	All
Age Group	Under 21 ..	3.90	3.82	3.90	—	—	—	3.90	3.82	3.90
	21-30 ..	3.98	3.38	3.96	—	—	—	3.98	3.38	3.96
	31-40 ..	3.54	2.36	3.51	3.00	—	3.00	3.52	2.36	3.49
	41-50 ..	2.99	2.72	2.93	2.98	2.67	2.89	2.99	2.71	2.93
	51-60 ..	2.64	2.12	2.50	2.69	2.23	2.48	2.65	2.17	2.49
	Over 60 ..	2.54	1.73	2.19	2.31	1.86	2.04	2.42	1.82	2.10
	All ..	3.50	2.45	3.38	2.71	2.14	2.46	3.43	2.33	3.25

of decline of F.E.V. (1 sec) with age is rather greater, even among the men without radiological pneumoconiosis or respiratory symptoms.

The relation between F.V.C. and age is illustrated at Table 4, which in general, shows the same trends as Table 3. The average F.V.C. of the men without radiological pneumoconiosis or respiratory symptoms is only slightly lower than that quoted by Miller and associates for normal subjects of the same age (MILLER, W. F. *et al.*, 1960).

The relation between F.E.V. per cent [i.e., $100 \times \text{F.E.V.}(1 \text{ sec})/\text{F.V.C.}$] and age

TABLE 4. AVERAGE F.V.C. (LITRES) IN TERMS OF RADIOLOGICAL PNEUMOCONIOSIS, RESPIRATORY SYMPTOMS AND AGE

Radiological Pneumoconiosis		Category 0			Category 1 or more			All		
Respiratory Symptoms		With-out	With	All	With-out	With	All	With-out	With	All
Age Group	Under 21 ..	4.74	4.71	4.74	—	—	—	4.74	4.71	4.74
	21-30 ..	5.09	4.77	5.08	—	—	—	5.09	4.77	5.08
	31-40 ..	4.69	3.97	4.67	4.06	—	4.06	4.67	3.97	4.65
	41-50 ..	4.20	3.87	4.13	4.17	3.71	4.04	4.20	3.84	4.12
	51-60 ..	3.74	3.29	3.62	3.90	3.39	3.67	3.79	3.34	3.64
	Over 60 ..	3.72	2.99	3.40	3.45	2.95	3.15	3.58	2.96	3.25
	All ..	4.57	3.63	4.46	3.88	3.26	3.60	4.51	3.48	4.34

is illustrated in Table 5. For the men without respiratory symptoms or radiological pneumoconiosis the average F.E.V. per cent falls steadily with age. The men without symptoms with category 1 or more pneumoconiosis show a similar trend. The

TABLE 5. AVERAGE F.E.V. PER CENT IN TERMS OF RADIOLOGICAL PNEUMOCONIOSIS, RESPIRATORY SYMPTOMS AND AGE

Age Group	Radiological Pneumoconiosis	Category 0			Category 1 or more			All		
		With- out	With	All	With- out	With	All	With- out	With	All
	Under 21 ..	82	82	82	—	—	—	82	82	82
	21-30 ..	78	70	78	—	—	—	78	70	78
	31-40 ..	75	58	75	73	—	73	75	58	75
	41-50 ..	72	68	71	72	73	72	72	69	71
	51-60 ..	71	64	69	70	65	68	71	64	69
	Over 60 ..	68	56	63	68	63	65	68	61	64
	All ..	76	65	75	70	65	68	75	65	74

F.E.V. per cent of the men with respiratory symptoms tends to be considerably lower than that of the men of the same age without symptoms. Among those with symptoms the F.E.V. per cent is lower for men with category 0 than for those with category 1 or more pneumoconiosis.

These results indicate that in the whole colliery population under consideration the F.E.V. per cent tends to decrease with increasing age. Among men without respiratory symptoms or radiological pneumoconiosis the fall is from 82 per cent for the under 21 years age group to 68 per cent in the over 60 years age group. This is in contrast to the findings of MILLER *et al.*, who reported a much smaller decrease in F.E.V. per cent from 87 per cent for the 20-29 years age group to 81.3 per cent for the 50-59 years age group, in a population of 77 normal male subjects. However, the value of 82 per cent for the average F.E.V. per cent for the under 21 age group agrees reasonably well with TIFFENEAU's figure of 83.8 per cent and GAENSLER's figure of 82.7 per cent for normal subjects. It is therefore possible that the greater rate of decrease of F.E.V. per cent with age observed among the coalminers may be associated with their occupational exposure. The effect of this factor is, however, by no means clear at this stage of the research. The studies of the relation between environmental exposure, X-ray category and pulmonary function at present being carried out should provide further information on this subject. Meanwhile, it appears that in this mining population the presence of respiratory symptoms tends to accentuate the rate of decrease of F.E.V. per cent with age.

F.E.V. (1 sec), F.V.C. and F.E.V. per cent in terms of sitting height

Table 6 shows the relation between average F.E.V. (1 sec) and sitting height.

TABLE 6. AVERAGE F.E.V. 1 SEC (LITRES) IN TERMS OF RADIOLOGICAL PNEUMOCONIOSIS, RESPIRATORY SYMPTOMS AND SITTING HEIGHT (CMS).

Sitting Height (cms).	Radiological Pneumoconiosis		Category 0			Category 1 or more			All		
	Respiratory Symptoms		With-out	With	All	With-out	With	All	With-out	With	All
78-79 ..			2.68	1.13	1.90	—	—	—	2.68	1.13	1.90
80-81 ..			2.88	—	2.88	—	—	—	2.88	—	2.88
82-83 ..			3.00	2.13	2.86	2.40	1.77	2.15	2.91	1.99	2.71
84-85 ..			3.01	2.34	2.91	2.58	1.85	2.22	2.96	2.14	2.79
86-87 ..			3.28	2.18	3.13	2.64	1.98	2.36	3.20	2.10	3.00
88-89 ..			3.45	2.42	3.37	2.61	1.89	2.28	3.38	2.16	3.22
90-91 ..			3.57	2.59	3.45	2.78	2.33	2.56	3.49	2.48	3.31
92-93 ..			3.67	2.52	3.52	2.74	1.72	2.50	3.59	2.39	3.43
94-95 ..			3.86	2.90	3.78	3.13	2.71	2.92	3.81	2.82	3.69
96-97 ..			4.18	—	4.18	3.63	3.12	3.29	4.15	3.12	4.05
98-99 ..			3.89	3.12	3.76	2.52	3.17	2.84	3.66	3.14	3.53
100-101 ..			3.98	—	3.98	—	—	—	3.98	—	3.98
102-103 ..			4.53	—	4.53	—	—	—	4.53	—	4.53
All ..			3.50	2.44	3.39	2.71	2.14	2.45	3.43	2.32	3.25

In all four sub-groups there is a marked tendency for F.E.V. (1 sec) to increase with sitting height. Among the men without respiratory symptoms, the average F.E.V. (1 sec) of those without radiological pneumoconiosis tends to be higher than that of those with pneumoconiosis. This is largely a reflection of the fact that F.E.V. (1 sec) decreases with age and that the men with pneumoconiosis are on average older than those who have not developed the condition.

The relation between F.V.C. and sitting height is illustrated at Table 7 which in general shows the same trends as Table 6.

Reference to Table 8 shows that there is no tendency towards a positive relation between F.E.V. per cent and sitting height among the men without radiological pneumoconiosis or respiratory symptoms. On the other hand, among the men with category 1 or more pneumoconiosis but without symptoms, the average F.E.V. per cent tends to increase slightly with sitting height, and when the men with symptoms are considered this tendency becomes more definite.

Linear combinations of F.E.V. (1 sec) and F.V.C.

From these results it appears that in the mining population under consideration

F.E.V. per cent is correlated with age among the men with and without both pneumoconiosis and respiratory symptoms, and with sitting height among the men with respiratory symptoms. It was therefore decided to investigate the correlation with age and sitting height of other simple combinations of F.E.V. (1 sec) and F.V.C., in an attempt to arrive at an index of ventilatory function independent of these two

TABLE 7. AVERAGE F.V.C. (LITRES) IN TERMS OF RADIOLOGICAL PNEUMOCONIOSIS, RESPIRATORY SYMPTOMS AND SITTING HEIGHT (CMS).

	Radiological Pneumoconiosis	Category 0			Category 1 or more			All		
		With- out	With	All	With- out	With	All	With- out	With	All
	Respiratory Symptoms									
(Sitting Heights cms).	78-79 ..	3.10	2.37	2.74	—	—	—	3.10	2.37	2.74
	80-81 ..	3.56	—	3.56	—	—	—	3.56	—	3.56
	82-83 ..	3.74	3.22	3.66	3.49	2.90	3.25	3.70	3.09	3.57
	84-85 ..	3.95	3.71	3.91	3.61	3.10	3.36	3.91	3.47	3.82
	86-87 ..	4.30	3.35	4.17	3.58	2.95	3.31	4.21	3.19	4.03
	88-89 ..	4.50	3.48	4.42	3.77	3.01	3.42	4.44	3.24	4.28
	90-91 ..	4.66	3.72	4.54	4.01	3.45	3.74	4.60	3.61	4.42
	92-93 ..	4.81	3.84	4.69	4.18	3.13	3.94	4.76	3.73	4.62
	94-95 ..	5.03	4.11	4.96	4.28	3.75	4.02	4.98	3.95	4.85
	96-97 ..	5.34	—	5.34	6.00	4.22	4.81	5.38	4.22	5.26
	98-99 ..	5.36	3.97	5.13	3.42	4.43	3.92	5.04	4.20	4.83
	100-101 ..	5.25	—	5.25	—	—	—	5.25	—	5.25
	102-103 ..	6.00	—	6.00	—	—	—	6.00	—	6.00
	All ..	4.57	3.64	4.47	3.89	3.26	3.61	4.51	3.49	4.35

physical factors. In the first place it was decided to consider an index formed by a linear combination of F.E.V. (1 sec) and F.V.C. of the form $[F.V.C. + \alpha F.E.V. (1 \text{ sec})]$, where α is a variable parameter which may take any value, positive, zero or negative [i.e., the index covers the whole range of values formed by the sum of the F.V.C. and any positive or negative multiple of the F.E.V. (1 sec.)]. The corresponding correlation co-efficient obviously depends on the value of α , for when α is zero it represents the correlation of age and sitting height with F.V.C. alone, and when α is infinite it represents the correlation of age and sitting height with F.E.V. (1 sec) alone. As α takes all values, positive and negative, the correlation of $[F.V.C. + \alpha F.E.V. (1 \text{ sec.})]$ with age and sitting height attains one maximum and one minimum value. At the maximum the correlation is the highest that can be reached

TABLE 8. AVERAGE F.E.V. PER CENT IN TERMS OF RADIOLOGICAL PNEUMOCONIOSIS, RESPIRATORY SYMPTOMS AND SITTING HEIGHT (CMS).

Radiological Pneumoconiosis		Category 0			Category 1 or more			All		
Respiratory Symptoms		With-out	With	All	With-out	With	All	With-out	With	All
Sitting Height (cms).	78-79 ..	85	45	65	—	—	—	85	45	65
	80-81 ..	79	—	79	—	—	—	79	—	79
	82-83 ..	81	65	78	65	65	65	78	65	76
	84-85 ..	75	59	73	72	58	65	75	59	71
	86-87 ..	76	64	74	74	66	71	76	65	74
	88-89 ..	76	69	75	69	62	66	75	66	74
	90-91 ..	76	68	75	71	69	70	76	68	74
	92-93 ..	76	64	74	65	55	63	75	63	73
	94-95 ..	77	67	76	72	72	72	77	69	76
	96-97 ..	79	—	79	65	75	72	78	75	78
	98-99 ..	71	75	72	75	75	75	72	75	72
	100-101 ..	72	—	72	—	—	—	72	—	72
	102-103 ..	75	—	75	—	—	—	75	—	75
	All ..	76	65	75	70	65	68	76	65	74

for any linear function of F.V.C. and F.E.V. (1 sec) on the one hand, and age and sitting height on the other, while at the minimum value the correlation is the lowest (i.e., the index shows its least dependence on age and sitting height).

An approach of this kind, which is based mainly on mathematical considerations, will not necessarily lead to conclusions which may be interpreted directly in basic physiological terms. Nevertheless, the application of a statistical analysis provides the only valid means of investigating whether or not any particular combination of F.E.V. (1 sec) and F.V.C. has the required properties, and on these grounds the approach is considered to be justifiable.

In view of the possibility that the presence of respiratory symptoms might affect the relationship, it was decided to consider the men with and without symptoms separately in the calculations. As no systematic differences between the men with and without pneumoconiosis had been observed in the preceding analysis, it was not considered worthwhile to make any further sub-division in terms of category 0 and category 1 or more pneumoconiosis. The estimates of α corresponding to the maximum and minimum values of the correlation for the men with and without respiratory symptoms are summarized at Table 9(a). The values for maximum

correlation show a considerable difference between the men with and without respiratory symptoms. In the case of minimum correlation, however, the value of α obtained for both groups is approximately equal to -1 . This means that among all the linear combinations of F.E.V. (1 sec) and F.V.C. the function [F.V.C. - F.E.V. (1 sec)] is the least well correlated with age and sitting height. It is interesting to note that this function, which corresponds to that part of the forced vital capacity expired after the first second, is capable of direct interpretation in physiological terms.

TABLE 9. CORRELATION OF AGE AND SITTING HEIGHT WITH LINEAR COMBINATIONS OF F.V.C. and F.E.V. (1 sec) OF THE FORM [F.V.C. + α F.E.V.]

(a) VALUES OF α FOR MAXIMUM AND MINIMUM CORRELATION

Respiratory symptoms	Without	With
Maximum correlation ..	-7.69	0.45
Minimum correlation ..	-1.02	-1.08

(b) MAGNITUDE OF MULTIPLE CORRELATION CO-EFFICIENTS

Respiratory symptoms	Without	With
F.E.V. (alone)	0.75	0.69
F.V.C. (alone)	0.68	0.72
Maximum correlation ..	0.76 ($\alpha = -7.69$)	0.73 ($\alpha = 0.45$)
Minimum correlation ..	0.42 ($\alpha = -1.02$)	0.094 ($\alpha = -1.08$)

Having derived the values of α giving maximum and minimum correlation with age and sitting height, the next step is to compare the corresponding correlation co-efficients with those derived using F.E.V. (1 sec) alone and F.V.C. alone. Details of these correlation co-efficients [relating age and sitting height to F.E.V. (1 sec) alone, F.V.C. alone and the maximum and minimum linear correlations of the two measurements] are given in Table 9(b). The maximum correlation co-efficients using linear combinations of F.E.V. (1 sec) and F.V.C. are very similar to those obtained using F.E.V. (1 sec) or F.V.C. alone. This shows that, from the point of view of correlation with age and sitting height, the best linear combination of F.E.V. (1 sec) and F.V.C. provides little further information than is contained in the F.E.V. (1 sec) alone.

Of the minimum correlation co-efficients one (for the men with respiratory symptoms) is small in comparison with the correlations between age and sitting height on the one hand, and either F.E.V. (1 sec) or F.V.C. alone on the other, and does not differ significantly from zero. The other co-efficient (for the men without respiratory symptoms) is of the same order of magnitude as that for F.E.V. (1 sec)

or F.V.C. alone, and is significantly different from zero. Thus it appears that there is no linear combination of F.E.V. (1 sec) and F.V.C. for this population which is uncorrelated with age and sitting height.

Linear Combinations of the Logarithms of F.E.V. (1 sec) and F.V.C.

In view of the lack of success in finding a linear combination of F.E.V. (1 sec) and F.V.C. independent of age and height, a second index of ventilatory function was considered, viz., that formed by linear combinations of the logarithms of F.E.V. (1 sec) and F.V.C. of the form $[\log F.V.C. + \beta \log F.E.V.]$, where β can take any value, positive or negative. In this way we can obtain an index based on the product of F.V.C. and any positive or negative power of F.E.V. (1 sec).

TABLE 10. CORRELATION OF AGE AND SITTING HEIGHT WITH LINEAR COMBINATIONS OF THE LOGARITHMS OF F.V.C. AND F.E.V. (1 SEC) OF THE FORM $[\log F.V.C. + \beta \log F.E.V.]$

(a) VALUES OF β FOR MAXIMUM AND MINIMUM CORRELATIONS

Respiratory symptoms	Without	With
Maximum correlation ..	5.30	0.07
Minimum correlation ..	-0.69	-0.89

(b) MAGNITUDE OF MULTIPLE CORRELATION CO-EFFICIENTS

Respiratory symptoms	Without	With
log F.E.V. (alone) ..	0.71	0.51
log F.V.C. (alone) ..	0.66	0.58
Maximum correlation ..	0.71 ($\beta = 5.30$)	0.59 ($\beta = 0.07$)
Minimum correlation ..	0.34 ($\beta = -0.69$)	0.22 ($\beta = -0.89$)

The estimates of β relating to the maximum and minimum correlations are given in Table 10(a). There is a considerable difference in the values corresponding to the maximum correlation for men with and without respiratory symptoms. In the case of the minimum correlation, however, the estimates of β are both of the order of -0.8. This means that the least correlation with age and sitting height occurs for a function of the form $\log F.V.C. - 0.8 \log F.E.V. = \log[(F.V.C.)/(F.E.V.)^{0.8}]$. This function is less well correlated with age and sitting height than is the Tiffeneau Ratio, which corresponds to the function $-(\log F.V.C. - \log F.E.V.)$.

The values of the multiple correlation co-efficients corresponding to F.E.V. (1 sec) alone, F.V.C. alone and the maximum and minimum correlations are shown in Table 10(b). As in Table 9(b), it is apparent that the maximum correlation is little different from the correlation with F.E.V. (1 sec) or F.V.C. alone. In the case of the minimum correlation co-efficients both values are lower than the corresponding

co-efficients for F.E.V. (1 sec) and F.V.C. alone. Both, however, are significantly greater than zero, indicating that there is no linear combination of the logarithms of F.E.V. (1 sec) and F.V.C. which is completely independent of age and sitting height in this population.

4. CONCLUSION

It is concluded that in this population of working coalminers examined at a colliery in Scotland, there is no simple combination of F.E.V. (1 sec) and F.V.C. which is independent of age and sitting height.

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APPENDIX 1

Respiratory Symptoms Questionnaire

Preamble

"I am going to ask you some questions about your chest, about cough and spit for example. Please try and answer 'yes' or 'no' but if you do not understand a question then ask me about it."

Cough

- | | | |
|---|--------|---|
| Do you cough when you get up or first thing in the morning? | Yes/No | 1 |
| Do you cough during the rest of the day—I don't mean at the end of the shift? | Yes/No | 2 |
| (if the answer to 2 is "yes" go on to 3. If "no" go on to 4). | | |

Do you cough like this on most days for as much as 3 months in the year? Yes/No 3

Phlegm

Do you bring up phlegm when you get up or first thing in the morning? Yes/No 4

Do you bring up phlegm during the rest of the day? Yes/No 5
(If the answer to 5 is "yes" go on to 6. If "no" go on to 7).

Do you bring up phlegm like this on most days for as much as 3 months in the year? Yes/No 6

Breathlessness

Do you have to walk slower than other people on the level? Yes/No 7

Wheezing

Do you ever have wheezing or whistling in your chest—I don't mean when you have a cold. Yes/No 8

Weather

Does the weather affect your chest? Yes/No 9

Smoking

Do you smoke? Yes/No 10

If yes: cigarettes per week: 11

oz. tobacco per week: 12

If no: Have you ever smoked as much as 10 cigarettes a day for 10 years? Yes/No 13

Chest Illness

In the last three years have you had a chest illness that has kept you off work for more than a week? Yes/No 14

If yes: What did the doctor say it was? 15

Respiratory symptoms to be diagnosed if positive answers are given to either
(a) one or other (or both) of Questions 3 and 6, together with one (or more) of Questions 7, 8, 9 and 14 (i.e., persistent cough or persistent phlegm, together with either breathlessness or wheeze or weather affecting the chest or previous chest illness),
or (b) both Questions 8 and 9 (i.e., wheeze and weather affecting chest).

NOTE

J. R. HODKINSON

The Institute of Hygiene at the Caroline Institute, Stockholm

ON 16 March 1961 I had the opportunity of spending a few hours at the Institute of Hygiene (director Professor Lars Friberg) in Stockholm. The Caroline Institute is the medical faculty of the University of Stockholm, but also embraces many specialized national institutes for teaching and research. During the last twenty years its buildings have been concentrated on an attractive and secluded site not far from the city centre. The Institute of Hygiene belongs partly to the Caroline Institute and partly to the Institute of Public Health, a government institute concerned with the routine surveillance both of occupational hygiene and other aspects of hygiene of national importance, especially in relation to foodstuffs.

In addition to its teaching responsibilities, the Institute of Hygiene pursues a research programme which includes pneumoconiosis, airborne dust measurement, urban air-pollution and industrial toxicology.

The history and extent of pneumoconiosis in Sweden is well described in Ahlmark, Bruce and Nystrom's recent book *Silicosis and other Pneumoconioses in Sweden* (Heinemann, 1960). Routine dust-measurements in the ceramic, brick and foundry industries use the American midget impinger because the American standards of maximum permissible dust concentration are applied, and these are difficult to interpret in relation to other instruments, such as the thermal precipitator, which do not disaggregate the dust or are more efficient in depositing sub-micron particles. Sweden possesses many iron-ore mines and a few coal-mines, but no systematic, routine dust-measurements are made there. Most of the mines, however, make some measurements with the konimeter (Witwatersrand or Sartorius-H.S. types), counting all particles visible in dark-field illumination and regarding concentrations less than about 400 particles cm^{-3} as tolerable. A few mines measure dust by the Leitz Tyndalloscope, but do not seem to have any general system for interpreting the results.

As a step towards evolving a routine procedure for dust measurement, the Institute of Hygiene is organizing comparative trials in an iron mine of the konimeter, thermal-precipitator, midget-impinger and membrane (millipore) filter, the last taking both short-period samples for microscope counting and long-period samples without coarse-particle elimination) for weighing and composition analysis. A suitable membrane-filter sampler has been made with a small battery-driven pump on the lines recently described in this journal by Sherwood and Greenhalgh (vol. 2, pp. 127-132, 1960).

The institute has a long-term project to estimate maximum permissible dust-concentrations by experiments on laboratory animals breathing re-dispersed mine dusts.

Traffic air-pollution in Stockholm is being analyzed chemically and the biological effect of the constituents is being tested on rabbits in a number of ways, especially by comparing the rate of clearance from the lung, in the same animal, of aerosols which do or do not contain these constituents. A number of refined techniques have been used to produce the carrier aerosols. At present it is proposed to dissolve gold stearate, the gold being the weak, gamma-emitting isotope 198, in stearin, which is then sprayed and allowed to solidify, and then undergoes a further stage of evaporation and condensation to form an aerosol of equal-sized stearin particles each with a radioactive nucleus of gold stearate. The lung clearance of the animal, and the accumulation of the products in other organs, can then be followed readily by gamma-radiation detectors.

The chief toxicological problem under study is cadmium poisoning in the electric-accumulator industry.

The laboratories of the Institute of Hygiene are well equipped, efficient and pleasant, and are soon to be extended. It was clear from the warmth of their welcome that the staff followed occupational hygiene research in other countries with great interest and would always be glad to receive foreign visitors and exchange information abroad.

J. R. HODKINSON

*Safety in Mines Research Establishment,
Ministry of Power,
Sheffield.*

NEWS

Index-hand-book of cardiovascular agents

THE National Academy of Sciences, National Research Council, Washington, D.C., announces the publication of the first volume of a three volume publication drawn from 13,427 scientific papers, monographs and reviews. Each entry is reduced to a few lines and indexed according to chemical and biomedical terms; the object is to provide an index to cardiovascular literature with entries which are informative enough to reduce substantially the time required by the investigator for library search.

The bulk of the present volume consists of more than 100,000 entries in alphabetical order which constitute the "Index-Handbook" proper. The publication also contains a list of periodicals covered, detailed directions for its most efficient use, and a guide to abbreviations used. Special features include the standardization of all chemical names, translation of all titles of papers with notation of original language, and extensive cross-referencing of standardized biological and medical subject headings.

The price of the volume is \$15 and it can be ordered from the Printing and Publishing Office, National Academy of Sciences—National Research Council, 2101 Constitution Avenue, N.W., Washington 25, D.C.

The work of the Cardiovascular Literature Research Project is supported by a research grant from the National Heart Institute, National Institutes of Health; and is directed by Dr. Isaac D. Welt. It is an activity of the Division of Medical Sciences—one of the eight divisions of the National Academy of Sciences—National Research Council—a private organization of distinguished scientists devoted to the furtherance of science for the general welfare.

Refinery emissions

THOSE interested in air pollution problems in general and in petroleum refineries in particular will be interested in a new bulletin prepared by the U.S. Public Health Service, Division of Air Pollution. *Atmospheric Emissions from Petroleum Refineries* is a 56-page bulletin which describes the processes of the petroleum refinery, the types and sources of atmospheric emissions, and the applicable control methods. The publication is well illustrated with photographs, drawings, flow charts, and tables. Methods, factors and examples are given for the calculation of the atmospheric load of various emissions. The appendices also include an outline summary of control methods and a glossary of refinery terms.

This bulletin can be purchased from the Superintendent of Documents, U.S. Government Printing Office, Washington 25, D.C. Specify Public Health Service Publication No. 763. The price is 30 cents per copy.

The New Institute of Industrial Hygiene and Air Pollution of the University of Montreal
THIS Institute was established in May 1960 in Montreal, Canada, and was approved

by the Quebec Ministry of Health under a federal-provincial agreement. Funds were provided by the Department of National Health and Welfare in order to initiate the project.

Following upon extensive discussions between Dr. Kingsley Kay, Senior Scientific Consultant, Department of National Health and Welfare, Canada, and Dr. F. J. Tourangeau, Director of Industrial Hygiene, Quebec Ministry of Health, in regard to the need for a comprehensive University research and teaching program on occupational health and air pollution in Canada, a survey financed by the Department of National Health and Welfare was carried out in several countries where institutes devoted to the subject are in operation. The survey showed particularly that an impressive amount of research is being carried out in all the industrialized countries visited. Furthermore comprehensive teaching programs covering medical, engineering and scientific aspects of the subject were being conducted at a level which had never been approached in Canada. Among the Institutes visited were the Karolinska Institute in Stockholm, Sweden, and the Institute of Occupational Health in Helsinki, Finland. It was notable that the budget of the Institute of Occupational Health in Helsinki amounted to some \$600,000. Finland has a population of about 7,000,000, less than half that of Canada.

The Province of Quebec has a population of almost 5,000,000 and is becoming rapidly industrialized. From two-thirds rural some fifteen years ago, its population has become two-thirds urban. Such a situation necessitates an adaptation of the working population to industrial life and gives rise to health problems which directly or indirectly are related to industrial production. It indicates the importance and the necessity of applied research in these domains both for the interests of the workers and of industry itself.

The plan of the proposed Institute is shown in the accompanying chart and covers a 7 to 10 year period to be approached in two stages.

The first stage provides for a three-year period of development of industrial hygiene and air pollution research projects in the Institute and in existing special departments of the University, this stage to be supported with the assistance of a group of consultants attached to the Institute. The Institute directorial and consulting staff maintain contact with the projects providing public health orientation as required and being responsible for initiating, co-ordinating and evaluating research projects. The Institute will also establish contacts with industrial organizations and fund-granting agencies and otherwise assist the participating University departments, some of which will carry out research under a contractual agreement with the Institute.

A number of distinguished consultants have lent their services in organizing the program: Dr. Lucien Dautrebande, Professor at the University of Liège, Dr. Enrico Vigliani, Director of the Clinica Del Lavoro, University of Milan, Dr. N. V. Hendricks, Senior Engineering Associate of the Esso Research and Engineering Company, Linden, N.J., Mr. H. Rozovsky, B.Sc., B.Eng., a Toronto Engineering Consultant, Dr. D. D. Irish of the Dow Chemical Company, Midland, Michigan, and Dr. Eugene Doroschuk, Physical Fitness Laboratory, University of Illinois.

The first stage of the Institute plan is now operating. There has been a series of grants-in-aid from the Department of National Health and Welfare. The International Chemical Workers Union has also made a grant for research. The Esso

Research and Engineering Corporation has contributed the services of its senior engineer associate, Dr. N. V. Hendricks, as consultant. There were during the fiscal year 1959-60 a grant to the Department of Physiology of the University of Montreal to cover a study on the pneumoconstriction effect of dust and on the pneumodilatation effect of certain aerosols on the lungs; another to Dr. Hans Selye, Institute of Experimental Medicine and Surgery of the University to assist in a study of the mechanism of penetration of toxic substances through the skin. These projects were initiated by the Institute and are considered extramural projects. There was also a grant to the Institute from the Department of National Health and Welfare to study the insecticide problem in relation to health in the Province of Quebec. This project is the first intramural project of the Institute.

The second stage of the development of the Institute covering a period of about 4 to 7 years would involve the provision of specialized personnel, laboratory space and equipment so that some research projects and teaching could be concentrated in the Institute where a congregation of specialists would permit a team approach to the many current industrial hygiene and air pollution problems requiring investigation. Whether facilities existing in other University departments should be duplicated would be considered in each case with the aid of the views of the consultants and an advisory committee.

The staff of the Institute now includes the Director, Dr. F. J. Tourangeau, who is also Professor of Industrial Health and Air Pollution, an Assistant Director, Mr. Sarto Plamondon who has been named Associate-Professor of Industrial Hygiene, Dr. Kingsley Kay as Senior Consultant on a part-time honorary basis, and consultants in toxicology, physiology, physiological hygiene and in industrial hygiene engineering. Other consultants in the fields of chemistry, physics, otology, ophthalmology and psychological hygiene will be secured.

The teaching program will be made a subject of special study by organizational staff and consultants in collaboration with University authorities and appropriate professional organizations. It will be directed towards undergraduates as well as graduates in science, medicine, nursing, engineering and chemistry.

Institute of Industrial Hygiene and Air Pollution
School of Hygiene, University of Montreal

Professor of Industrial Hygiene
and Air Pollution

Consultants
and
Advisory
Committees

Administration of research
grants and related develop-
ments including field
operations.

*Toxicology and
Dermatology*
Assessment of in-
secticides, skin
penetration studies, etc.

*Physiological and
Psychological Hygiene*
Work and sports problems,
biological ageing, job
adaptation, etc.

*Ophthalmology
and Otolaryngology*
Noise in industry,
industrial cataract,
usual task assessment
etc.

*Industrial Hygiene
Engineering*
Ultrasonic dust
collection, hospital
problems, etc.

*Chemistry and
Physics*
Analysis for toxic
contaminants, radia-
tion analysis, etc.

ERRATUM

Author Index to Vol. 3

It is regretted that the following entry was omitted from the index

BRICARD, J., 278 (B)

Vol.
1961

EDITORIAL

THIS issue contains the papers presented and discussions at the meeting on Health Physics which was held by the British Occupational Hygiene Society on Wednesday, 4 January 1961, at the London School of Hygiene and Tropical Medicine. The President of the Society, Dr. J. C. Gilson, occupied the Chair during the proceedings and, in welcoming those present, said that the British Occupational Hygiene Society had as its aim the promotion of the development of occupational hygiene in all its aspects, but that this was the first meeting wholly devoted to Health Physics. He hoped that it would be first of many at which those concerned with health physics would meet to exchange information and ideas with those working in other aspects of occupational hygiene. In the coming decade there would be a further expansion of the uses of sources of radiation in industry and elsewhere, and it was important to disseminate, as widely as possible, information about the means of monitoring the environment and measuring the dose to the individual. This was particularly important at the present time when new factory regulations were shortly coming into force. The manuscripts and discussions were collated by Mr. R. J. Sherwood.

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1961/62

AN INTRODUCTION TO HEALTH PHYSICS MEASUREMENTS

R. J. SHERWOOD

Health Physics Division, A.E.R.E. Harwell

(Received 20 April, 1961)

Abstract—After a brief introduction to the principles applied in controlling radiation hazards, this paper outlines the radiations commonly encountered and defines units of measurement.

The maximum permissible levels at present applied are presented in detail, and a brief summary of the main types of health physics measurement and the instruments commonly used is given.

HEALTH physics as a branch of occupational hygiene has two unique features. The first is that although the term health physics is still faintly mystical, the potential health hazard it deals with, that from ionizing radiation in any form, is so popularized as to be practically sensational. Unfortunately, dramatization does little to help establish control in practice. Radiological safety can only be achieved by a proper evaluation of any possible hazard, for which it is usually necessary to make measurements, and to interpret the results in the light of theoretical and experimental studies, and of human experience. The control of most common toxic materials can frequently be achieved by simple engineering design, supported where necessary by some measure of personal protection, and routine monitoring of the potential hazard is seldom required. The greater potential hazard from ionizing radiation, however, frequently requires the setting up of an adequate monitoring programme to ensure that the safety precautions are functioning satisfactorily; it is the highly developed techniques of measurement that are the second unique feature of health physics.

Early experiments with sources of ionizing radiation, and their use in medical and industrial applications showed that harmful effects could be produced unless proper controls were applied. Those suffering through occupational exposure have included the pioneers of X-rays, medical radiographers, luminizers, and miners of pitchblende in Central Europe. It should be appreciated that although the total number of people who have suffered its effects has been small, the incidence of disease has been high when related to the number at risk.

It was perhaps in part due to the small numbers affected that an appreciation of the hazards grew only slowly, and that a hazard to one profession, X-ray workers, was not immediately recognized in another form in the luminizing industry. While the total number of people harmed has been small, the potential risk to the individual was quite unacceptable by the standards applied today. It is certain that the history of radiation induced disease has been largely due to a lack of appreciation



FIG. 1. Loading an isotope shipment into an aircraft.

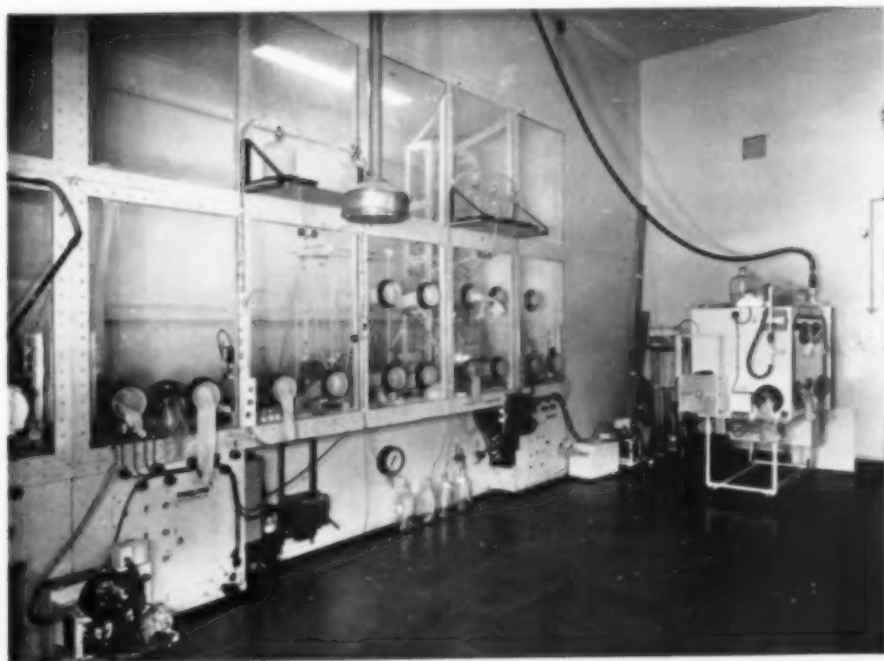


FIG. 2. Glove boxes for handling open sources.

[facing p. 90]



FIG. 3. Radiochemical laboratory.

of the hazard by those concerned, lack of the measurements needed to maintain health control and, until the 1920's, lack of standards by which to judge conditions.

Although overexposure to ionizing radiations may manifest itself in a variety of ways, and assessment of a given situation may often prove difficult, two basic forms of hazard can be distinguished. The radiation may be emitted either from a source outside the human body (termed external radiation) or from a source which has penetrated into the body, through inhalation, skin penetration or ingestion (termed internal radiation). Whereas exposure to external radiation ceases when the source is removed, or is reduced when the source is shielded, exposure to internal radiation from a source distributed within the body, or concentrated in specific organs, is governed largely by the physical and chemical nature of the source, and by the normal biological processes of the body.

Neither of these two forms of hazard is unique. Ultra-violet and infra-red radiation can affect the body from external sources, and the more conventional toxic materials commonly cause ill effects by penetrating into the body; in either case the body may have no sensing mechanism at levels which may cause ill effects after long delay periods. Perhaps the only remarkable features of ionizing radiation are that certain forms are extremely penetrating, and that sources commonly encountered may produce amounts of radiation many times the permitted limit.

Although the methods for controlling radiation are in essence the same as those for conventional hazards, the strictness of control needed may be much greater than normally required. To control the external radiation hazard, use is made of distance, time and shielding; with a little imagination analogies can be made with radiant heat and ultra-violet radiation.

These principles are demonstrated in Fig. 1 which shows the loading of a radioactive source into a compartment in the wing of an aircraft. Exposure of the passengers during a long flight is minimized by the distance between the wing tip and the passenger cabin; the loading operation takes but a few seconds and a short tong is adequate. For the journey by car to the airport, where the driver is comparatively close to the source for some time, extra control is achieved by the lead shielding container.

To control the internal hazard, the principles of containment and cleanliness are applied. Fig. 2 shows glove boxes in which the radioactive substances may be handled completely isolated from the workers' environment. Fig. 3 shows a modern radiochemical laboratory in the design of which ease of cleaning is a primary consideration. These demonstrate a natural extension of the methods used for controlling common toxic materials, such as lead.

The relative magnitude of toxicity of radioactive and inactive materials is illustrated in Table I. Caution must be taken in interpreting the relative hazards of the radioactive materials as, being expressed in terms of mass, short lived substances which may in fact be relatively innocuous, appear to be extremely hazardous. To compare relative toxicities of radioactive substances, their half-lives must be taken into account. The values for inactive substances are those published by the AMERICAN CONFERENCE OF GOVERNMENT INDUSTRIAL HYGIENISTS (1960), and all values are rounded to the nearest factor of 10.

Classification of nuclides by toxicity based on activity is published in a CODE OF PRACTICE (1957) and in SAFE HANDLING OF RADIOISOTOPES (1958). The most useful

references on nuclides are probably the G. E. CHART OF THE NUCLIDES (1956) and RADIOISOTOPE DATA, ALLEN *et al.* (1961).

TABLE 1. COMPARISON OF MAXIMUM PERMISSIBLE CONCENTRATIONS IN AIR OF VARIOUS STABLE AND RADIOACTIVE SUBSTANCES ON A MASS BASIS

Inactive	Mg/m ³	Active
Carbon dioxide	10 ⁴	
Trichloroethylene	10 ³	
Carbon monoxide	10 ²	
Hydrogen cyanide	10	
D.D.T.	1	
Chromic acid	10 ⁻¹	Natural uranium
Organic mercury	10 ⁻²	Nickel-59
Beryllium	10 ⁻³	Carbon-14
	10 ⁻⁴	
	10 ⁻⁵	Uranium-233
	10 ⁻⁶	Tritium
	10 ⁻⁷	Caesium-137
	10 ⁻⁸	Radium-226
	10 ⁻⁹	Strontium-90
	10 ⁻¹⁰	Iodine-131
	10 ⁻¹¹	Sodium-24
	10 ⁻¹²	Astatine-211
	10 ⁻¹³	Thoron

The greater hazard from radioactive substances is fortunately balanced by the availability and relative simplicity of quick methods of detection and measurement.

From the tragic experience of the pioneers and others exposed to radiation in the past, such as luminizers and survivors from the bombing of Hiroshima and Nagasaki, from accidents and medical usage today, and from animal experimentation, it has been possible to derive maximum permissible levels for exposure of different groups of people.

THE FORMS OF RADIATION AND UNITS OF MEASUREMENT

The form that a radiation hazard may take depends in part on the type of radiation encountered. The types of radiation considered in this paper are restricted to α , β , γ and X.

TABLE 2. SUMMARY OF HAZARDS

Nuclide Emitting	Hazard	
	External	Internal
α -particles	None	Very serious
β -particles	To skin and eyes only	Serious
γ -rays	To whole body and internal organs	Not normally significant

NOTE.—X-rays are identical with γ -rays but are generated by high voltage machines. Unlike γ -rays, they may be switched off when not required.

α -Particles, emitted by the heavy elements, create an intense trail of ionization but travel only short distances, 3–8 cm in air, 25–100 μ in water. β -Particles,

producing less intense ionization, travel greater distances, typically about 1 cm in water. X- and γ -radiations, which differ only in origin, travel freely between interactions with matter, and have a great range. A comparison of the hazards that may arise is shown in Table 2.

It may be noted that even though neutrons are specifically excluded from this paper, the fundamental permissible doses later described are still applicable.

Units of measurement

Units of measurement are required to describe a quantity of radioactivity, that is the radioactive size of a source of radiation, and the rate that the size diminishes; to define the energy of the radiation emitted (which governs its penetrability); and to express the hazard to human beings in terms of radiation dose. To establish common standards, an INTERNATIONAL COMMISSION ON RADIOLOGICAL UNITS has been set up, and its most recent recommendations were published in 1956.

1. *Quantity of activity.* The unit of quantity of activity, originally derived from 1 g of radium, is the curie. One curie is the amount of a radioactive substance that decays at the rate of 3.7×10^{10} atoms/sec. The rate of emission of particles or photons is dependent on this quantity, but is not necessarily identical with it.

Activity may for convenience be expressed in units representing one-thousandth of a curie (millicurie) or one millionth (microcurie).

$$1\text{c} = 10^3\text{mc} = 10^6\mu\text{c}.$$

A useful relationship is that $1\mu\text{c} = 2.2$ disintegrations/min.

2. *Rate of decay.* Radioactive decay is a process governed by an exponential law, thus $A_2 = A_1 e^{-\lambda t}$

where A_1 = activity at commencement of a period of time t

A_2 = activity at the end of period

λ = decay constant

As the decay constant is difficult to visualize, it is usual to express decay in terms of half-life; that is the time taken for a source to lose one half its activity. This time is a characteristic constant for a given nuclide (a particular species of atom having a given number of neutrons and protons in the nucleus).

Half-life corresponds to $0.693/\lambda$.

3. *Energy of radiation.* Whereas the activity of a source may be likened to the brightness of a lamp, the energy of the radiation may be likened (most strictly) to the colour of the light emitted.

The energy is measured in terms of the electron volt (eV) which is the kinetic energy acquired by an electron falling through a potential difference of 1 volt. Energy may also be expressed in units of a thousand eV (keV) and a million eV (MeV)

$$1\text{ MeV} = 10^3\text{ keV} = 10^6\text{ eV},$$

$$1\text{ eV} = 1.6 \times 10^{-12}\text{ erg}.$$

$$\text{The energy of electromagnetic radiation in eV} = \frac{1.242 \times 10^4}{\text{wavelength } (\text{\AA})}.$$

4. *Units of dose.* The permitted levels of exposure are based on the concept of dose. To determine the exposure of people to X- or γ -radiation, it is the practice to measure the ionization produced in air (the electric charge set free). For this, the unit of exposure dose, the Roentgen (r) is used, the definition being "the quantity of X- or γ -radiation such that the associated corpuscular emission per 0.001293 g of air produces, in air, ions carrying one electrostatic unit of quantity of electricity of either sign".

Unfortunately this cannot be used for all forms of radiation and it does not necessarily represent the dose absorbed by the human body. To assess the absorbed dose (which cannot be measured directly at levels of concern) units of Rad are used. One rad is an absorbed dose of 100 ergs/g of the substance irradiated—for health physics, this is tissue. This can be compared to the roentgen which delivers about 88 ergs/g to air, 94–97 to tissue.

The relative biological effectiveness (RBE) of radiation may not depend solely on the energy delivered, so that in expressing fundamental permissible levels, the unit of RBE dose is used—this is the rem. This can be briefly defined as an amount of energy absorbed from a given form of radiation which produces the same biological effect in an organ as 1 rad of X-rays of 250 kV.

All these units may be subdivided into thousandths and millionths,

$$1 \text{ r} = 10^3 \text{ mr} = 10^6 \mu\text{r}$$

$$1 \text{ rad} = 10^3 \text{ mrad} = 10^6 \mu\text{rad}$$

$$1 \text{ rem} = 10^3 \text{ mrem} = 10^6 \mu\text{rem}$$

The inter-relation of these units is not always simple but, for the radiations considered in this paper, the roentgen, the rad and the rem are taken to be quantitatively the same for external radiation. For assessing the internal radiation hazard in practice, the unit of significance is the microcurie (μc) as it is a measure of the amount of radioactivity within the body.

Maximum permissible doses

The formulation of standards to permit assessment of radiation hazards was pioneered in this country by the British X-Ray and Radium Protection Committee established in 1921. In 1929 an INTERNATIONAL COMMISSION was created, and recommended internationally acceptable limits. These have been revised periodically in the light of experience and the growth of an atomic energy industry, the most recent RECOMMENDATIONS being issued in 1959. Public concern on the possible increase of exposure to radiation in recent years led to the creation of a MEDICAL RESEARCH COUNCIL COMMITTEE to report on the Hazards to Man of Nuclear and Allied Radiations (1956 and 1960). At the international level, the UNITED NATIONS ORGANIZATION has appointed a similar scientific committee, which has published one report to date (1958).

It is not possible to review here all the information on which present day recommendations are based. The underlying philosophy is demonstrated by the statement in the (1960) M.R.C. report that "It is not possible to state categorically that any dose of radiation will be entirely without consequences. It is therefore necessary that maximum permissible levels of exposure for individuals and for

populations should be based on practical considerations which balance the possible risks of harm against the advantages of using radiation in particular circumstances."

The International Commission defines permissible doses in a way that could hardly be bettered:

"The permissible dose for an *individual* is that dose, accumulated over a long period of time or resulting from a single exposure, which, in the light of present knowledge, carries a negligible probability of severe somatic or genetic injuries; furthermore, it is such a dose that any effects that ensue more frequently are limited to those of a minor nature that would not be considered unacceptable by the exposed individual and by competent medical authorities.

Any severe somatic injuries (e.g. leukemia) that might result from exposure of individuals to the permissible dose would be limited to an exceedingly small fraction of the exposed group; effects such as shortening of life span, which might be expected to occur more frequently, would be very slight and would likely be hidden by normal biological variations. The permissible doses can therefore be expected to produce effects that could be detectable only by statistical methods applied to large groups.

The permissible dose to the gonads for the *whole population* is limited primarily by considerations with respect to genetic effects."

For the purposes of defining permissible levels the International Commission considers four main categories of exposure:

- (1) Occupational exposure.
- (2) Exposure of special groups:
 - (a) Adults who work in the vicinity of controlled areas, but who are not themselves employed on work causing exposure to radiation.
 - (b) Adults who enter controlled areas occasionally in the course of their duties, but are not regarded as radiation workers.
 - (c) Members of the public living in the neighbourhood of controlled areas.
- (3) Exposure of the population at large.
- (4) Medical exposure.

Persons in category 2(a) and 2(b) are treated identically, but lower levels are set for 2(c), as the group is likely to include children.

The I.C.R.P. make no recommendations concerning the dose to the individual arising from medical exposures, other than to individuals exposed in the course of their occupations. Individual doses resulting from medical exposure are excluded from the recommendations; the contribution of medical exposure to the genetic dose of the population at large, however, is considered. Doses resulting from natural background radiation, which are of the order of 100 mr/year in U.K., are excluded from all the I.C.R.P. recommendations.

The present basic maximum permissible doses are summarized in Table 3 together with the corresponding average permissible dose rates. It will be seen that the permissible dose for occupational workers—those considered fit and under medical supervision—is now governed by a formula which allows them to have accumulated a maximum dose to whole body, gonads, blood-forming organs and lens of eye of 5 rems for each year of age after 18. This corresponds to a constant

TABLE 3. MAXIMUM PERMISSIBLE DOSES AND CORRESPONDING DOSE RATES

Part of body exposed	Radiation workers		Non-radiation workers		Individual members of public	
	Permissible dose (rem.)	Corresponding average 40 hr/week dose-rate (mrads/hr)	Permissible dose (rem/y)	Corresponding average 40 hr/week dose-rate (mrads/hr)	Permissible dose (rem/y)	Corresponding average 168 hr/week dose rate (mrads/hr)
Whole body, gonads, blood forming organs, lens of eye	5 (Age-18) 3 per 13 weeks	2.5 6	1.5	0.8	0.5	0.06
Skin, thyroid, bone	30 per year 8 per 13 weeks	} 15	3	1.5	3	0.34
Hands, forearms, feet and ankles	75 per year 20 per 13 weeks	} 40	—	—	—	—
Other single organs	15 per year 4 per 13 weeks	— —	1.5 —	— —	1.5 —	— —

dose rate of 2.5 mrad/hr during 40 hr per week exposure. For comparison the background dose rate out-of-doors due to natural activity is of the order of 0.01 mrad/hr.

For the purposes of calculating the dose to the skin and the eyes, the depths of sensitive tissue below the skin surface of the Standard Man are assumed to be 70 μ and 3 mm respectively (7 and 300 mg/cm²).

In the event of exposure to more than one form of radiation, or of irradiation of a number of internal organs, consideration must be given to the total dose received.

If a radiation worker's exposure history is unknown when the 5 rems/year age formula is introduced, it must be assumed that he has received the maximum dose allowed by the formula. If he is known to have had more than is allowed by the formula, he should not be permitted to have more than 5 rems in any year until his average has dropped to that permitted by the formula.

When a person is occupationally exposed before the age of 18, he must not exceed 5 rems in any year below that age, and the dose accumulated by the age of 30 shall not exceed 60 rems. The M.R.C. COMMITTEE ON PROTECTION AGAINST IONIZING RADIATION (1960) recommends that exposure below the age of 18 should be restricted to 1.5 rems/year; it also recommends that the contribution of occupational exposure to the genetic dose (over a period of 30 years) of the whole population should be restricted to 1 rem per head of population. It should be noted that the SEALED SOURCES REGULATIONS (1961) issued by the Factory Department forbids occupational exposure in factories under the age of 18. This is consistent with other special regulations for safety and health, and with Sections 58 and 59 of the 1937 Factories Act.

Accidental high exposure

I.C.R.P. recommend that a single accidental dose of not more than 25 rems shall not affect a radiation worker's status. If his accumulated dose then exceeds that permitted by the age formula, the excess need not be included in future calculation of his dose. The M.R.C. Committee advise that the excess dose should, if possible, be worked off during the 5 years following the accident under conditions of reduced exposure.

Emergency exposure

Emergency work should be planned on the basis that an individual will not receive a dose of more than 12 rems; if his accumulated dose is then in excess of that permitted by the formula, it shall be worked off within 5 years. Women of reproductive age shall not be subjected to such emergency exposure.

The M.R.C. COMMITTEE ON PROTECTION AGAINST IONIZING RADIATIONS (1960) has recommended maximum permissible doses for members of the general public for exposure which might result from an incident at an atomic energy establishment.

Exposure of the population

The I.C.R.P. recommends that the genetic dose, over a period of 30 years, averaged over the whole population, in addition to natural background, should not

exceed 5 rems plus the lowest practicable contribution from medical exposure; the Commission illustrate how such a dose might be apportioned. While accepting this value as an upper limit, the M.R.C. Committee consider that the operative figure should in fact be determined by considering the levels which should be allowed for different sources of radiation, the contribution from each being held to the lowest practicable level.

In this connexion it is to be noted that the COMMITTEE ON RADIOLOGICAL HAZARDS TO PATIENTS (1960) recently estimated that the total genetic dose to patients from medical usage of ionizing radiation could readily be reduced from the present 19.3 mr/y to 6 mr/y if the current best practice was applied in all hospitals.

Maximum permissible concentration

In addition to the basic permissible levels I.C.R.P. recommend derived permissible body burdens and concentrations in air and water. These have been calculated from the concept of a Standard Man, whose anatomy, chemistry, and behaviour have been defined. A few examples of permissible body burdens and air concentrations for 40 hr/week exposure of radiation and non-radiation workers are shown in Table 4. The values for non-radiation workers are derived from the Commission's recommendation that the dose to their gonads or whole body should not exceed 1.5 rems/y—corresponding to $\frac{1}{3}$ that for radiation workers, and the dose to other organs should not exceed $\frac{1}{10}$ that for radiation workers.

When the uptake of a mixture of nuclides in several organs is such that the combined exposure constitutes essentially whole body exposure, the permissible concentrations for non-radiation workers must be reduced by a further factor of 3 or more.

The M.R.C. Committee interpret these values as applying to average concentrations over a period of a year.

Where significant doses of external radiation are received, a corresponding reduction of maximum permissible concentrations must be made.

In view of the uncertainties associated with collecting air samples representing the true exposure of individual workers, it is common practice to keep levels below $\frac{1}{10}$ the permitted maximum, and, where more than one permissible concentration is quoted, to select the more restrictive value; it is not then generally necessary to calculate the doses received or add the results to the external radiation records. Although I.C.R.P. accept that concentrations may be allowed to vary, provided that the total intake in any 13 week period does not exceed that allowed from exposure to constant maximum permissible levels, it advises that the safest and simplest procedure is always to keep levels at or below the recommended values. Although higher concentrations are generally permitted for insoluble forms of most nuclides, this relaxation must only be used with great discretion, and it should be borne in mind that the value of routine urine analysis is correspondingly diminished. Also derived from I.C.R.P. recommendations, maximum permissible concentrations for continuous exposure of individual members of the public are shown in Table 5; as the solubility of the contaminants is seldom known, the more restrictive value for each nuclide is given. Also shown in Table 5 are average permissible concentrations suggested for the whole public; where the total body or the gonads are critical organs, the values are taken from an illustrated apportionment of the

TABLE 4. MAXIMUM PERMISSIBLE BODY BURDENS AND CONCENTRATIONS IN AIR FOR 40 HR/WEEK EXPOSURE

Nuclide	Soluble insoluble	Critical organ	Radiation workers			Non-radiation workers		
			Body burden (μC)	Concentration in air		Body burden (μC)	Concentration in air	
				($\mu\text{C}/\text{cm}^3$)	(dpm/m ³)		($\mu\text{C}/\text{cm}^3$)	(dpm/m ³)
H ³ (H ₂ O)	Sol	Body Tissue	10 ³	5 × 10 ⁻⁶	10 ⁷	3 × 10 ²	1.5 × 10 ⁻⁸	3 × 10 ³
C ¹⁴ (CO ₂)	Sol	Fat	300	4 × 10 ⁻⁶	10 ⁷	30	4 × 10 ⁻⁷	10 ³
Na ²⁴	Sol	Small intestine	—	10 ⁻⁶	2 × 10 ⁴	—	10 ⁻⁷	2 × 10 ³
	Insol	Lower large intestine	—	10 ⁻⁷	2 × 10 ³	—	10 ⁻⁸	2 × 10 ⁴
P ³²	Sol	Bone	6	7 × 10 ⁻⁸	1.5 × 10 ³	0.6	7 × 10 ⁻⁹	1.5 × 10 ⁴
	Insol	Lung	—	8 × 10 ⁻⁸	2 × 10 ³	—	8 × 10 ⁻⁹	2 × 10 ⁴
S ³⁵	Sol	Testis	90	3 × 10 ⁻⁷	7 × 10 ³	30	10 ⁻⁷	2 × 10 ³
	Insol	Lung	—	3 × 10 ⁻⁷	7 × 10 ³	—	3 × 10 ⁻⁸	7 × 10 ⁴
C ⁶⁰	Sol	Lower large intestine	—	3 × 10 ⁻⁷	7 × 10 ³	—	3 × 10 ⁻⁸	7 × 10 ⁴
	Insol	Lung	—	9 × 10 ⁻⁹	2 × 10 ⁴	—	9 × 10 ⁻¹⁰	2 × 10 ³
Sr ⁹⁰	Sol	Bone	4	3 × 10 ⁻⁸	7 × 10 ⁴	0.4	3 × 10 ⁻⁹	7 × 10 ³
	Insol	Lung	—	4 × 10 ⁻⁸	10 ³	—	4 × 10 ⁻⁹	10 ⁴
Sr ⁹⁰	Sol	Bone	2	3 × 10 ⁻¹⁰	7 × 10 ²	0.2	3 × 10 ⁻¹¹	70
	Insol	Lung	—	5 × 10 ⁻⁹	10 ⁴	—	5 × 10 ⁻¹⁰	10 ³
I ¹³¹	Sol	Thyroid	7 × 10 ⁻¹	9 × 10 ⁻⁹	2 × 10	7 × 10 ⁻²	9 × 10 ⁻¹⁰	2 × 10 ³
	Insol	Lower large intestine	—	3 × 10 ⁻⁷	7 × 10 ³	—	3 × 10 ⁻⁸	7 × 10 ⁴
		Lung	—	6 × 10 ⁻⁸	1.5 × 10 ³	—	—	—
Cs ¹³⁷	Sol	Total body	30	—	—	—	8 × 10 ⁻⁹	2 × 10 ⁴
	Sol	Liver	—	10 ⁻⁸	2 × 10 ⁴	4	10 ⁻⁹	2 × 10 ³
	Insol	Lung	—	3 × 10 ⁻¹¹	70	—	3 × 10 ⁻¹²	7
Ra ²²⁶	Sol	Bone	10 ⁻¹	2 × 10 ⁻⁷	5 × 10 ⁴	10 ⁻²	2 × 10 ⁻⁸	5 × 10 ⁴
	Insol	Lower large intestine	—	7 × 10 ⁻¹¹	3 × 10 ²	—	7 × 10 ⁻¹²	30
U ^{nat}	Sol	Kidney	5 × 10 ⁻³	6 × 10 ⁻¹¹	3 × 10 ²	5 × 10 ⁻⁴	6 × 10 ⁻¹²	30
	Insol	Lung	—	2 × 10 ⁻¹²	4	—	2 × 10 ⁻¹³	0.4
Pu ²³⁹	Sol	Bone	4 × 10 ⁻²	4 × 10 ⁻¹¹	10 ²	4 × 10 ⁻³	4 × 10 ⁻¹²	10
	Insol	Lung	—	1.2 × 10 ⁻¹²	3	—	1.2 × 10 ⁻¹³	0.3
Unidentified α-activity, if β-activity, if elements heavier than thallium can be ex- cluded	—	—	—	3 × 10 ⁻¹⁰	7 × 10 ²	—	3 × 10 ⁻¹¹	70

suggested permissible total of 5 rems/30 y, and would give rise to a genetic dose of 1.5 rems.

In addition to these normal permissible levels, maximum permissible levels of dietary contamination after the accidental release of radioactive material from a nuclear reactor have been defined by the M.R.C. COMMITTEE ON PROTECTION AGAINST IONIZING RADIATIONS (1960).

TABLE 5. MAXIMUM PERMISSIBLE CONCENTRATIONS IN AIR AND WATER FOR CONTINUOUS EXPOSURE OF THE GENERAL POPULATION

Nuclide	Individual members of public		Suggested average over whole public	
	Concentration in Water ($\mu\text{C}/\text{cm}^3$)	Concentration in Air ($\mu\text{C}/\text{cm}^3$)	Concentration in Water ($\mu\text{C}/\text{cm}^3$)	Concentration in Air ($\mu\text{C}/\text{cm}^3$)
$\text{H}^3(\text{H}_2\text{O})$	3×10^{-8}	2×10^{-7}	3×10^{-4}	2×10^{-8}
$\text{C}^{14}(\text{CO}_2)$	8×10^{-4}	10^{-7}	3×10^{-4}	3×10^{-8}
Na^{24}	3×10^{-6}	5×10^{-9}	10^{-5}	2×10^{-9}
P^{32}	2×10^{-5}	2×10^{-9}	7×10^{-6}	7×10^{-10}
S^{35}	6×10^{-5}	9×10^{-9}	6×10^{-6}	9×10^{-10}
Co^{60}	3×10^{-5}	3×10^{-10}	10^{-5}	10^{-10}
Sr^{89}	10^{-5}	10^{-9}	3×10^{-6}	3×10^{-10}
Sr^{90}	10^{-7}	10^{-11}	3×10^{-8}	3×10^{-12}
I^{131}	2×10^{-6}	3×10^{-10}	7×10^{-7}	10^{-10}
Cs^{137}	2×10^{-5}	5×10^{-10}	2×10^{-6}	2×10^{-10}
Ra^{226}	10^{-8}	10^{-12}	2×10^{-9}	2×10^{-13}
U^{nat}	2×10^{-5}	2×10^{-12}	7×10^{-6}	7×10^{-13}
Pu^{239}	5×10^{-6}	6×10^{-14}	2×10^{-6}	2×10^{-14}
Unidentified α -activity	10^{-8}	4×10^{-14}	—	—
β -activity if elements heavier than thallium can be excluded	7×10^{-7}	10^{-11}	—	—

Permissible levels of surface contamination

A further criterion for determining the potential hazard arising from a radioactive substance is that of surface contamination. The spread of radioactive material on surfaces may present either an internal or an external hazard; the measurement of surface activity is a monitoring method much valued in the field because of its inherent speed and simplicity. As this simplicity does not necessarily extend to the interpretation of results of such measurements, it is usually wise to make judicious selection of what and where to monitor.

The accurate assessment of the potential hazard arising from surface contamination is seldom possible from the information commonly available to the operational health physicist; it is therefore necessary to apply somewhat arbitrarily derived permissible levels. The values shown in Table 6 are on the way to being recognized as standards in the United Kingdom, being applied in the Atomic Energy Authority and similar to those recommended in the CODE OF PRACTICE (1957). Experience suggests that they are of the right order of magnitude.

Low toxicity α -emitters consist of short lived nuclides, natural uranium and all

uranium isotopes, natural thorium, thorium-232, and thorium-228 and -230 when diluted to a specific activity of the same order as natural thorium.

TABLE 6. MAXIMUM PERMISSIBLE LEVELS OF SURFACE CONTAMINATION

Radioactive material	Personal clothing Inactive areas Low activity areas ($\mu\text{C}/\text{cm}^2$)	Protective clothing High activity areas ($\mu\text{C}/\text{cm}^2$)	Skin ($\mu\text{C}/\text{cm}^2$)
Principal α -emitters	10^{-5}	10^{-4}	10^{-5}
Low toxicity α -emitters	10^{-4}	10^{-3}	10^{-5}
All β -emitters	10^{-4}	10^{-3}	10^{-4}

In assessing the potential hazard arising from localized spots above these values, measurements may be averaged over inanimate surfaces of up to 300 cm² or for floors and other large areas, 1000 cm². The averaging area for skin is 100 cm², except for the hands where the whole area of one hand (300 cm²) may be used.

Although the assumptions made in deriving these levels are conservative, and no great precision of measurement is necessary, any serious relaxation (say by a factor of 10 or greater) should only be made in circumstances where the current and future use of the surface or article is known, and where it can be shown that no hazard will arise.

Summary of health physics measurements

As this paper is intended to serve as an introduction to those that follow on monitoring methods, a brief summary of common health physics measurements and the instruments in current use in the U.K. is shown in Table 7. This is not intended to be comprehensive, but merely to serve as a guide to the types and methods of measurement most frequently made.

CONCLUSION

As in all branches of occupational and public hygiene, it is essential to distinguish between *monitoring* a possible hazard, and its *control*. It must be stressed that good measurement can never rectify bad design of control devices—it can only detect it. To monitor any hazard successfully it is first necessary to identify that which is to be assessed; for instance it may be necessary to determine in a given situation whether β -dose to skin is likely to prove more restrictive than γ -dose to gonads, eyes, or whole body—or whether dose to hands may be limiting. Only when this is known will it be possible to ensure by dose rate measurement that no permissible dose is exceeded, or that no special monitoring arrangements, such as a β -sensitive pocket dosimeter, or dosimeter worn on the wrist, are necessary.

Secondly, it is necessary to know the performance and limitations of the instrument used in the particular conditions prevailing.

Finally, great care must be taken in interpreting any measurement—particularly

when the conditions in which it was made are not fully known. At best, the measurement represents the exposure of the instrument, and the possible errors in equating this to the exposure of a human being or a group must be carefully considered.

TABLE 7. MONITORING EQUIPMENT 1961

Health physics measurements	Device commonly used
1. External radiation dose to the body: (1) Whole body } (2) Hands }	{ Film badge { Pocket dosimeter
2. Rate at which external dose is received	Ionization chamber survey meter
3. Radioactive contamination of surfaces— (equipment, clothing, fixed surfaces, etc.)	{ α -scintillation probe on contamination monitor { β -Geiger probe on contamination monitor
4. Concentration or radioactive substances in air	Filter paper air sampler; separate installed α -scintillation or β -Geiger counter
5. Radioactive contamination of skin and clothes: (1) Hands	{ Installed α -proportional counter { Installed β -Geiger counter } or double scintillator
(2) Other parts of the body and clothes	{ α -scintillator probe on installed monitor { β -Geiger probe on installed monitor
6. Radioactivity in the body: (1) Direct measurement	{ Whole body γ -spectrometer { Iodine-in-thyroid monitor
(2) Measurement of excreta	{ Chemical treatment of urine or faeces followed by counting on installed equipment (as 4 above) { Radon-in-breath monitor

A programme of measurements such as for surface contamination must not be based solely on simplicity; the operational health physicist must always be on his guard against making a particular measurement just because it is simple. He must first consider the use he intends to make of any result, and whether he will be able to interpret the measurement properly.

Many reports on measurement methods were presented at the 1956 and 1958 UNITED NATIONS CONFERENCES ON THE PEACEFUL USES OF ATOMIC ENERGY at Geneva and at a conference at Risø in 1959.

In both 1956 and 1960 the M.R.C. Committee's Report on the HAZARDS TO MAN OF NUCLEAR AND ALLIED RADIATIONS summarized its general conclusions on the hazard from civil uses of radiation in the words:

"The general conclusion to be drawn from a consideration of the hazards inseparable from the application of ionizing radiations in peacetime is that at present there is no cause for alarm; but that, as all such radiations are potentially dangerous, their use should be the subject of constant and close scrutiny, and that adequate justification should be required for their employment on however

small a scale. There is a limit to the amount of radiation which any population or any individual can accept and we cannot afford to expend, without careful forethought, the margin which is now available to us."

It is certainly proper to assume that constant and close scrutiny must include adequate programmes of measurement.

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THE ROLE OF THE FILM BADGE IN PERSONNEL MONITORING

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Abstract—The reasons for using photographic films, rather than ionization chambers, for the large scale personnel monitoring of external radiation are given and the defects from which the film technique suffers are discussed. The way in which these defects may be overcome is illustrated by reference to the film dosimeter developed by the Radiological Protection Service, the functioning of which is described in detail. Finally, the organization required for the operation of a large scale film monitoring service is described and reference is made to the need for adequate ancillary services to deal with problems of over-exposure and the maintenance of cumulative records.

IN ORDER to ascertain that persons exposed to external sources of ionizing radiations are not receiving doses in excess of the recommended maximum permissible levels, it is necessary that they carry some form of personal radiation dosimeter. The two types of dosimeter commonly used for this purpose are the ionization chamber and the photographic film; the former depending upon the loss of charge which results from the ionization of the air between its electrodes and the latter upon the actinic response of the photographic emulsion to ionizing radiations.

Two types of ionization instruments are available. The first, which is simply an ionization chamber, requires an additional electrometer to measure the dose received by the instrument whilst the second, commonly called a pocket dosimeter or dosimeter, incorporates a quartz fibre electrometer and optical system whereby the dose received may be directly observed. This latter feature is a valuable asset particularly in operations of a non-routine nature where a continuous check on individual exposures is required. The simple ionization chamber is said to be unreliable if subjected to mechanical shock, whilst both instruments, in common with all ionization instruments, are liable to electrical leakage, the result of which is indistinguishable from exposure to ionizing radiation. These defects result in over-estimation of the doses received, and consequently they could impair an individual's dose history and lead to unnecessary investigations. Alternatively, there is an inevitable tendency to attribute any apparently inexplicable dose to leakage of the instrument. In addition, the sensitivity of the types of pocket dosimeter commonly available today varies markedly with radiation energy; the error, with an instrument calibrated with radium γ -radiation, amounting to about +40 per cent at an effective energy of about 50 keV and -40 per cent at an effective energy of about 20 keV.

The direct reading instrument is available with a choice of exposure ranges e.g. 0-0.5 r, 0-5 r and 0-50 r. By using a dosimeter having the 0-0.5 r range low levels of exposure can be measured but, should a slight over-exposure occur, the instrument will be discharged and the dose involved completely unknown. The

0-50 r instrument will cope with this problem but the smallest dose that can be measured with this instrument is above the average weekly permissible level. Thus, the simultaneous use of two instruments of differing sensitivities may be required.

This type of instrument can of course be used by unskilled personnel but it is essential for skilled staff to make regular checks of the calibration, leakage and mechanical condition if reliance is to be placed upon the readings. Furthermore, if ionization instruments are used as the sole means of monitoring, the doses must be carefully recorded at the time of measurement, for once the instrument has been recharged there is no means of checking whether it had been read and recorded correctly.

In considering the suitability of photographic films for monitoring purposes it must be realized that they are mass produced and therefore, in spite of careful quality control by the manufacturers, some variations in characteristics are to be expected from film to film and emulsion batch to emulsion batch. In order to minimize these effects it is therefore necessary to rely on production control and on laboratory checks on the fog-level and emulsion characteristics of sample films. The emulsions themselves exhibit some undesirable features when considered for the purposes of dose measurement, for example, they are subject to fogging due to background radiation, chemical action and heat and there may well be fading of the latent image if a considerable time elapses before development. Furthermore the emulsion characteristics can be appreciably affected by storage and processing conditions. It is inevitable that these defects will introduce errors, which may be appreciable when measuring low dose levels. In order to operate an efficient film service it is therefore essential to have adequately trained staff together with facilities for controlling developing conditions, maintaining standards and for investigating any film exhibiting an unusual appearance. With such an organization, errors are minimized and experience enables many effects due, for example, to the mis-handling of the film by the user, to be recognized.

In spite of the above defects the film has several advantages over the ionization chamber and is better adapted for the purposes of a large scale monitoring service. It is capable of recording doses due to X- or γ -rays having effective energies from about 10 keV upwards, β -rays from about 150 keV upwards and thermal neutrons, and also of indicating the type of radiation involved. It is also often possible to deduce from the film the manner in which the exposure was received; for example, whether the dose was received from a point source of radiation as a result of a single or multiple exposure or from a large area source (sharp or diffuse image of the filter), or, again, whether any airborne contamination was present due to faulty technique in handling open sources. Such information is of considerable value should conditions be such as to require a radiation survey to be carried out. In addition, the film is capable of recording a wide range of doses from less than one-fifth of the average weekly permissible level to very large over-exposures and it also provides a permanent record of the dose received. Its chief disadvantage is that it does not provide an immediate reading, as processing and evaluation inevitably introduce a delay in obtaining information about the dose received.

It is evident from the above considerations that both films and ionization chambers are of value in personnel monitoring. For a limited service either the film or ionization chamber could be employed but for a large scale service involving the

postal transmission of instruments and covering organizations where conditions of exposure, the types of radiation employed, and the degree of protection differ widely, there is no doubt that the film is the method of choice. In many circumstances there is of course much to be said for the simultaneous use of both methods.

The response of a photographic film to X- or γ -rays is markedly dependent upon the radiation energy as is shown in the upper curve of Fig. 1 and thus the radiation dose received by a monitoring film cannot be determined by a simple comparison of the film density with the densities of films exposed to known doses of radiation of a

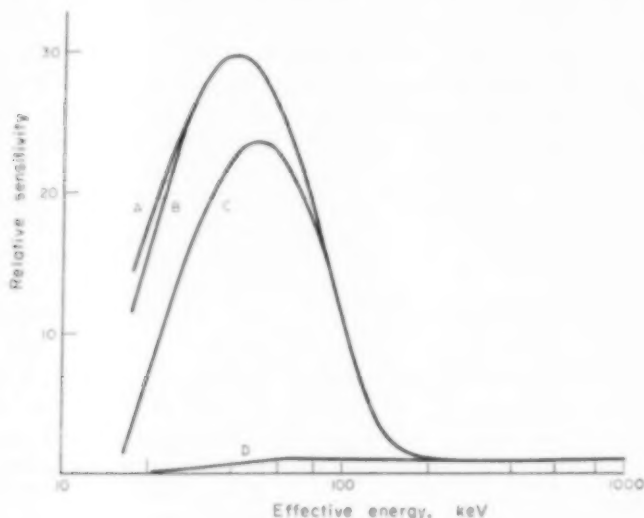


FIG. 1. Variation of sensitivity with effective energy for the fast emulsion of the Kodak R.M. Film. (a) unfiltered; (b) nylon filtered; (c) dural filtered; (d) tin/lead filtered.

particular energy. For accurate dosimetry it is essential either to know the energy of the radiation to which the film has been exposed, or in some way to make the film response independent of radiation energy. The former method is the more practicable and the majority of personnel film dosimeters in use today employ this technique. The method involves placing one or more absorbers of different atomic number and/or thickness in contact with the film wrapper, the different densities of the areas of the film beneath the filters then giving a measure of the selective transmission of the radiation and thus of its energy. The filter system employed in the holder developed by the Radiological Protection Service (Fig. 2) operates on this principle and provides a typical example. The holder comprises a nylon case which both holds the film and supports two pairs of metal filters in contact with it, the lower filter consisting of 0.012 in. lead plus 0.028 in. tin and the upper of 0.035 in. B.S. L72 duralumin. Part of the film is shielded by 0.070 in. nylon and an area is left unshielded.

The response to X- and γ -rays of the film beneath the various filters is shown in Fig. 1 and it will be noted that the increased film sensitivity to radiations in the effective energy range 80–200 keV is counterbalanced by increased absorption in the

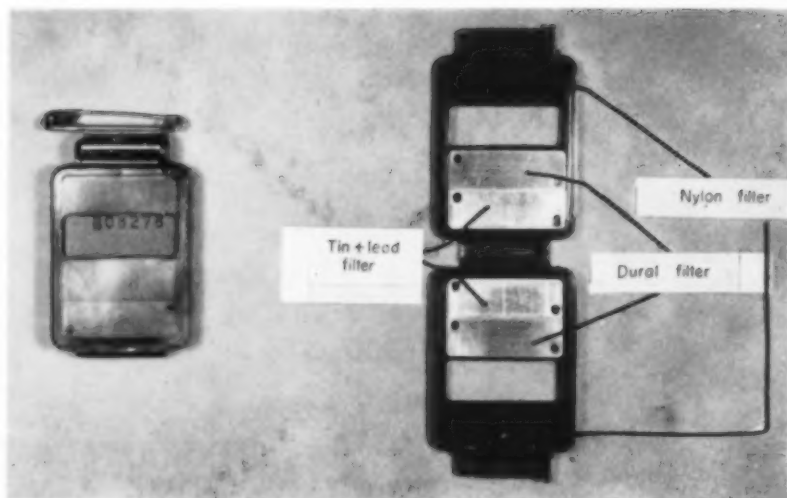


FIG. 2. The R.P.S. film holder.

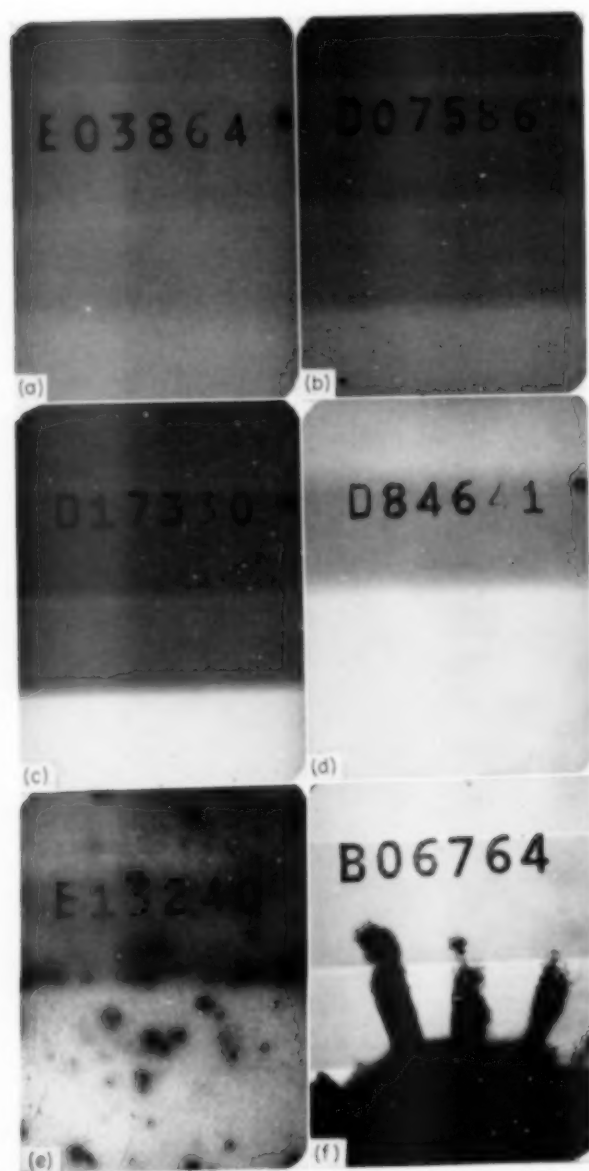


FIG. 3. Examples of monitoring films showing effect of (a) γ -radiation (b) 250 kV X-rays, (c) 80 kV X-rays, (d) β -rays, (e) β - and γ -radiation with "spots" due to contamination by radioactive material, (f) light fogging.

tin/lead filter. The sensitivity of the film beneath this filter is thus independent of energy above about 80 keV and doses of X- and γ -rays having effective energies greater than this value can be directly determined by a comparison of the film density beneath this filter with the densities of films exposed to known doses of, for example, radium γ -radiation. For radiations whose effective energy is less than 80 keV, the sensitivity of the filtered film is less than unity and a correction factor must be applied, this being determined from the ratio of the apparent doses beneath the tin/lead filtered and duralumin filtered film. As the effective radiation energy falls below about 50–60 keV the correction factors become very large due to the high absorption of the tin/lead filter and doses of such radiation are determined by comparison with standard films exposed in the laboratory to 30 keV X-radiation. In this case the effective radiation energy and thus the correction factor is determined from measurements of the apparent doses beneath the duralumin filtered and unfiltered portions of the film. It should be noted that the energies referred to in keV are effective radiation energies and are not to be confused with the kilovoltage applied to an X-ray tube. For example, radiations produced by an X-ray tube operating at 200 kV and filtered by a composite filter consisting of 1 mm Sn, 1 mm Cu and 1 mm Al will have an effective energy of about 120 keV.

The estimation of β -ray doses is similar to that described above for X- and γ -rays with the exception that the nylon filter is employed. The thickness of this filter is such as to stop all β -rays with an energy less than about 0.6 MeV, and the presence of a β -ray dose is thus clearly indicated by the contrast between the nylon shielded and unshielded areas of the film. It will be noted from Fig. 1 that the nylon filter produces negligible attenuation of X-radiation, except at very low energies.

Finally the film may also be employed for the measurement of doses of thermal neutrons. In order to do this half of the tin/lead filter is replaced by a cadmium/lead filter as cadmium has a high absorption cross section for thermal neutrons. In so far as γ -radiation is concerned the tin/lead and cadmium/lead filters will give essentially the same response; thermal neutron irradiation however will produce enhanced blackening beneath the cadmium/lead filter, due to the production of γ -radiation when the neutrons are captured by the cadmium, and the contrast between the tin/lead and cadmium/lead shielded areas thus provides a measure of the thermal neutron exposure.

Typical monitoring films illustrating some of the features described above are shown in Fig. 3.

The filter system described above and in particular the tin/lead filter has been designed to suit the response of a particular monitoring film. In this case it is the Kodak R.M. Film, which has emulsions of different sensitivities on either side of the film base. The emulsion on the front face is of high sensitivity, permitting doses ranging from about 20 mr to 5 r of 1 MeV X- or γ -radiation to be readily determined. Above 5 r, at a density of about 3.5, the less sensitive emulsion on rear of the film base then begins to respond, with the result that the density of the complete film continues to increase up to densities of 6.0 or more, corresponding to a dose of about 50 r of 1 MeV radiation. If it is necessary to measure doses in excess of this latter figure, or if a high range densitometer is not available, the front emulsion may easily be removed and the slow emulsion alone densitometered. By this means doses of up to 2000 r of 1 MeV radiation may be evaluated. At lower radiation energies

the film is far more sensitive, (see Fig. 1) and at its maximum sensitivity has an exposure range of < 1 mr to about 100 r. Fig. 4 shows dose-density curves for the Kodak film when exposed to radium γ -radiation.

A pertinent question applying to all types of personnel radiation monitors concerns the part of the body on which they should be carried since, being small in size, they are only capable of recording the dose received by a very limited area of the body. In general they are worn on the chest and there is some evidence to show that in this position the film indicates the mean body dose. This would not be true of course should there be narrow beams of radiation such as might escape from

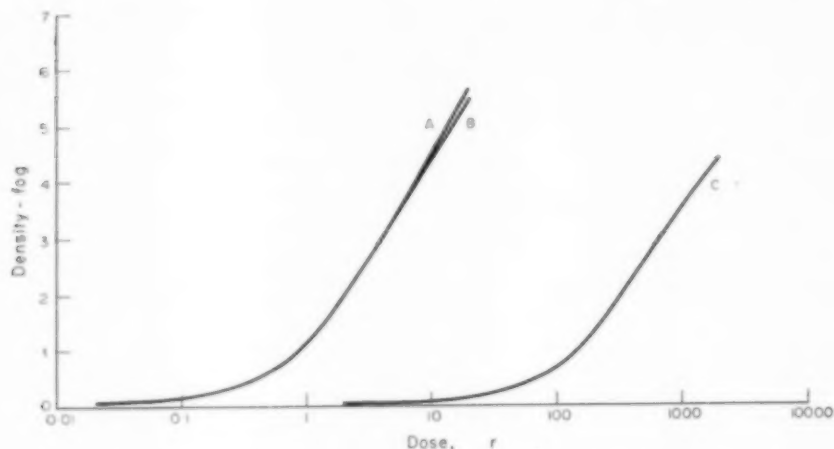


FIG. 4. Dose-density curve for Kodak R.M. film exposed to radium γ -radiation, (a) combined emulsions, (b) fast emulsion, (c) slow emulsion.

cracks in protective barriers, but these should have been located and eliminated in a survey of the installation before commencing routine operations. In some instances it is not sufficient to carry a film on the chest alone. This is particularly so, for example, in the case of persons who manipulate radioactive sources. In such a case the dose received by the hands may be 10 or more times greater than that to the trunk and it is then necessary to wear finger or wrist films. Although in some circumstances the interpretation of such films is difficult they do, at the very least, provide an indication of the adequacy or otherwise of the techniques being employed.

A film badge service of the type outlined above will yield results with an accuracy of the order of ± 20 per cent for radiation doses equal to or greater than the average weekly permissible level of 100 mr. Below this level the percentage error increases and the error is best expressed as a dose and not as a percentage. In the case of 1 MeV X- or γ -rays, the error is about ± 20 mr. This results from the fact that such a dose of 1 MeV radiation gives a net blackening of only about 0.02 above the fog level (about 0.20) of an unexposed film. Since the fog level from film to film may well vary by ± 0.01 or even more, it is impossible to be certain that such a small change in film density is due to a genuine radiation dose. The error is of course

much reduced for radiations of lower energy and amounts to about ± 1 mr for radiation with an effective energy of 40 keV. Where effective radiation energies of about 1 MeV are concerned there is therefore much to be said, from the point of view of accuracy, for the monitoring film being worn for periods of several weeks in cases where the weekly dose amounts to only a few milliroentgens. In order to operate a monitoring service in this way it would be necessary for a second film or dosimeter to be carried, which could be checked more frequently, and attention would have to be given to such questions as the fading of the latent image, and the build up of fog level due to chemical effects or high temperatures. An alternative approach would be to increase the film sensitivity to such radiation by, for example, placing scintillators in contact with the emulsion. Unfortunately it has been reported that the blackening of the film is then a function not only of dose but of dose rate. Attempts to overcome this failing are, however, in progress at the present time.

Although a film service may be operated in a number of ways the basic requirements in so far as organization, technical needs, etc., are concerned, are illustrated in the schematic diagram of the service operated by the R.P.S. (Fig. 5). This service is at present dealing with about 4,000 films per week, the films, in general, being worn for a two week period. Indeed with such a basic organization, and provided the necessary staff, accommodation and facilities are available, there is really no limit to the number of people who could be monitored. Fig. 5 is largely self-explanatory, and only two points are worthy of further mention.

Where the monitoring film shows a dose in excess of 300 mrad/week, or other unsatisfactory features such as contamination, the report to the employer is accompanied by a letter indicating the possible cause of the exposure and suggesting methods of preventing a recurrence. In many such cases investigation shows that the worker concerned had not in fact received the dose recorded by the film but had, for example, left the film in the source room overnight. However, where genuine doses have occurred and the employer is unable to rectify conditions, a radiation survey is carried out and recommendations made to correct any faulty techniques or protective measures. The use of punched cards for recording details of individual radiation exposures facilitates the assessment of cumulative doses and the statistical analysis of the results. However, complications may ensue when a person changes his employment, for no facilities exist at present for reporting the movements of radiation workers. Since such persons may abandon this type of work for several years and return to it at a later date the maintenance of lifetime records for such a person is obviously difficult. If movement information were available, and this would not be too difficult to arrange, then it would be a simple matter for the different dose records of an individual to be brought together. This problem is in fact being dealt with, in so far as industry is concerned, in that the draft Factory (Ionizing Radiations) Regulations require a prospective employee to provide a new employer with details of his previous radiation exposure.

Although the dose received by a radiation worker can be determined by personnel monitoring, this is neither practicable nor necessary for those who may work in the vicinity of a radiation installation, but who are not radiation workers. For this latter group, proper planning of an installation in conjunction, if necessary, with a radiation survey is the best means of ensuring that they are not exposed in excess of the appropriate permissible level. Indeed, proper planning is the most

important feature of radiation protection even in so far as radiation workers are concerned, for if an installation is properly designed it will make for both efficiency and safety.

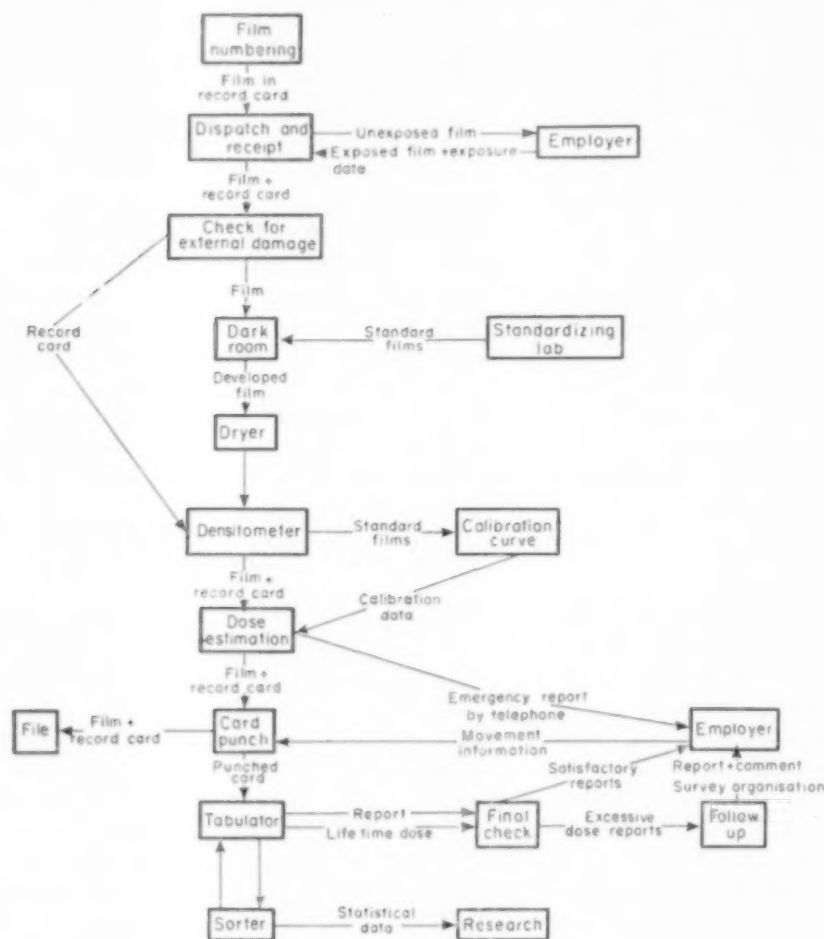


FIG. 5. Organization of a large scale monitoring service.

DISCUSSION

DR. G. J. FORTUIN, (Philips Industries Medical Service, Eindhoven, Holland). How do you record the undetectable dose in the punched card (e.g. 20 mr) and how do you take these very small weekly doses in calculating the 13-week exposure?

MR. B. E. JONES. Doses of less than 20 mr are recorded as 20 mr and the 13-week total would thus be "less than 130 mr", the films being worn for a 2-week period. On an annual basis the dose recorded would thus be 520 mr which is only about 1/10th of the permissible level for radiation workers and is indeed appreciably less than the permissible level for non-radiation workers in the vicinity of radiation installations (1.5 r/yr). It does not therefore give cause for concern although we would of course like to reduce the threshold sensitivity of the film.

MR. K. F. WILLIAMS, (The Steel Company of Wales Ltd., Port Talbot). Why is there a threshold of 20 mr? Does it exist because of background errors, chemical fog, heat effects, etc., during storage, or is there a physical threshold? If the latter, can the film be pre-dosed to overcome the threshold?

MR. B. E. JONES. The fog density of an unexposed monitoring film is about 0.20 and a dose of 20 mr of γ -radiation results in an increase in density of only about 0.02. Since the fog density itself may vary by ± 0.01 or more, apparent doses of less than 20 mr may or may not be genuine and the lower limit is therefore set at this value. Increase in fogging due to chemical effects, etc., does of course increase the error in determining low radiation doses. Pre-dosing the film would increase the apparent fog density and therefore increase the possible error.

MR. S. SMITH, (H.M. Chemical Inspector of Factories). Would Mr. Jones comment on the measurement of radiation (by means of film badges) of low energy, e.g. down to a few keV.

MR. B. E. JONES. This is possible in practice, the only difficulty being in determining the film sensitivity. To do this a suitable ionization chamber is required in order to measure accurately the dose delivered to the film. Until recently no such chambers were commercially available and we have therefore designed and constructed one ourselves. This will be working in the near future and we shall then be able to calibrate films at very low energies.

MR. W. A. LANGMEAD commented that he had had experience of measuring X-rays of 10 kV. Until recently, no ionization chambers were commercially available for measuring this quality radiation and it was necessary to construct one's own. The Victoreen Instrument Co. of America now produce chambers sensitive to these low energies, and it is thus possible to calibrate protection films at these energies. It is necessary for workers to wear the films beneath the clothing in view of the high absorption of these radiations in the clothing.

THE PRESIDENT. How many people are under film badge supervision by the Radiological Protection Service, and what proportion does this represent of all those so supervised. Is there any integrated national scheme for keeping records of all those people wearing film badges so that eventually we might get more information about the biological significance, if any, of low but measured doses of radiation?

MR. B. E. JONES. Some 10,000 workers are monitored at present, covering about 1500 organizations. About 8000 are continuously monitored the remainder being monitored periodically. It would, by reference to other monitoring services, be possible to determine what proportion of all monitored persons this represents but I do not have any information as to the numbers of radiation workers who are not monitored in any way. I would imagine that such numbers would be small. One difficulty in maintaining cumulative records is that at present we have no means of tracing a person who changes his employment or who leaves radiation work and subsequently returns.

MR. H. J. DUNSTER commented that a similar number of workers were monitored in the U.K.A.E.A.

MR. S. L. FRY, (J. Stone & Co., Charlton). For what length of time are film badges retained after exposure at Radiological Protection Service?

MR. B. E. JONES. At present all monitoring films are retained and I doubt if this procedure will change until some authoritative view is made known. If films are to be kept as evidence of the dose received then it will obviously be necessary to keep them for the period of the person's lifetime.

MR. G. C. DALE, (C.E.G.B.). Is any information available on the response of the R.P.S. Film Badge to γ -radiation above 3 MeV?

MR. B. E. JONES. We have not, as yet, calibrated films with radiation of energy greater than 3 MeV although we hope to do so in the near future.

MR. J. A. BONNELL, (C.E.G.B. Nuclear Health and Safety Department). Under the Nuclear Installations (Licensing and Insurance) Act 1960 the licensees of licensed sites had complete liability for injury or damage to persons or property due to ionizing radiation arising from the site. This liability existed for a period of 30 years. Furthermore, the draft Sealed Sources Regulations of the Factory Department excluded sites licensed under the 1960 Act and the Ministry of Power had the responsibility for health and safety at these sites, which was maintained by appropriate conditions attached to the licence. Clearly, therefore, the records of personnel employed at licensed sites would need to be kept for at least 30 years.

MR. I. K. B. LEGGE, (H.M. Factory Inspectorate). With regard to Mr. B. E. Jones' remarks concerning the difficulty of keeping cumulative radiation dose records for persons who change their employment, the meeting will be interested to know that requirements dealing with the transfer of such records are included in the second preliminary draft of the Factories (Ionizing Radiation)

Regulations. These will, of course, apply only to persons who are employed or have been employed in premises subject to the Factories Act.

The regulation referred to would require the employer of any person who has worn a film badge to supply him, when he leaves his employment, with details of the sum of the radiation doses the man has received during his period of employment. The employer would also have to send a copy of this record to the District Inspector of Factories. If this person then applied for employment at another factory for work involving the use of ionizing radiations which would require him to wear a film badge, he would have to notify his new employer of his previous employment and produce the copy of his radiation dose record. If this record should not be available the new employer would have to apply to the District Inspector of Factories for a copy. This should assist in the keeping of lifetime cumulative doses for persons employed in factories or other premises subject to the Factories Act.

THE POCKET DOSIMETER

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PROBABLY the most widely used method of measuring the dose received by a person is the film badge. Its chief advantages are cheapness, small size and the capability of integrating over long periods without significant loss. Apart from its use as a personal monitor, photographic film can be used for the measurement of high and low dose rates and in places where the dose changes rapidly with position. The blackening of a film does not change linearly with exposure but is usually an "S" curve; increasing slowly at first then a rapid increase followed by a flattened off. If exposure is increased much beyond this point a phenomenon known as "solarization" occurs and the blackening falls off again with increasing exposure. Because of this non-linearity of density with exposure it is necessary to calibrate each type of film carefully over the full range of exposure for which it will be used. The density for a given exposure will vary greatly with the conditions of development and it is necessary to take great care to keep time and temperature constant and to agitate the films during development.

As would be expected from the presence of elements of high atomic number (silver, bromine and iodine) the energy response of a film to X- and γ -radiation is poor at the lower energies.

This peculiarity in response at low energies can be corrected by use of a filter and the response can be brought within about 10 per cent over a range of several MeV down to 60 keV, after which there is virtually a cut-off. Because of this cut-off it is usual in personal dosimetry to have only part of the film covered with the filter so that softer radiation can be recorded and some estimate made of the dose. The estimate will not be very accurate unless the energy of the radiation is known, and attempts have been made by using a series of filters of different metals to improve assessment of dose of low energy radiations. Such methods are rather complicated in use, however, and with normal exposure to mixed radiation the single filter gives fair results.

With β -radiation, the response of the emulsion itself is reasonably independent of energy but the presence of wrappings to protect it from light causes attenuation of the lower energies so that the blackening from a given dose of β -rays of effective energy 0.3 MeV, is only about a quarter of that for an effective energy of 0.6 MeV.

The sensitivity of normal film emulsions to neutrons is quite low (about 100th of that to X-rays in terms of equal biological dose). If, however, a cadmium filter is used the response to thermal neutrons is greatly increased and about the same sensitivity can be obtained for X- and γ -rays and thermal neutrons.

For fast neutrons it is necessary to resort to the more laborious procedure of

track counting. A layer of hydrogenous material such as polythene is sandwiched between a pair of nuclear emulsion plates. Tracks are produced by recoil protons and are counted in the field of a microscope.

Pocket dosimeters consist essentially of a small ionization chamber which may be charged to a preset voltage, and the subsequent discharge measured by an electrometer.

In one form, the electrometer may be combined with the charging device, and as this can be used with a number of ionization chambers, it can result in considerable economy.

The main disadvantage, however, is that the user can only make a check on the accumulated dosage by taking his chamber back to the electrometer. In most cases this procedure is unsatisfactory and inconvenient.

Because of this, the quartz-fibre electrometer has been developed, which is a combined ionization chamber and electrometer, and so designed to be sufficiently portable to be carried on the person.

This pocket dosimeter is roughly the size of an ordinary fountain pen and comprises a small ionization chamber—to the inner electrode of which is attached a gilded quartz fibre in the form of a hairpin movement. As in the case of earlier devices, it has a rubber end-cap which can be removed to enable the instrument to be charged by the now exposed electrode system (that is the inner electrode and the outer case of the instrument). The charging action causes the quartz fibre movement to take up a standard position on a scale. In general charging devices are used which produce a variable voltage since it is convenient to be able to adjust the applied voltage whilst viewing the scale of the instrument.

This is accomplished by inserting the pocket dosimeter into a socket in the charging unit, which automatically makes the necessary electrical connexion to the battery or generator. The socket is constructed partly of a transparent material and below this is a small electric lamp powered by the battery which is switched on during the charging operation. Alternatively the charger may be used in association with an external light source. It is thus possible to apply the eye to the eyepiece end of the dosimeter and view the graticule or scale while adjusting the charging operation.

Apart from the battery type of charger employing a high-voltage battery, other types are available using a low voltage battery with a d.c. converter and a transistor circuit to step up the input. Another version uses a small magneto, the mechanical energy being applied by the motion of a handwheel.

Still another version makes use of a piezo-electric material (barium titanate). The material produces sufficient electric charge under mechanical pressure for charging dosimeters; and chargers based upon this principle are those in general use today.

Referring to the dosimeter itself. In the usual type the quartz fibre movement is set to zero on the scale during the charging operation. It is then removed and the end cap replaced. The instrument is then ready for use.

It is a wise precaution, however, before issue to check the position of the quartz fibre on the scale independently of the charger to ensure that the adjustment has been properly made. This is done by holding the dosimeter up to the light and viewing through the eyepiece. This is possible for the rubber end-cap is provided with a transparent insert.

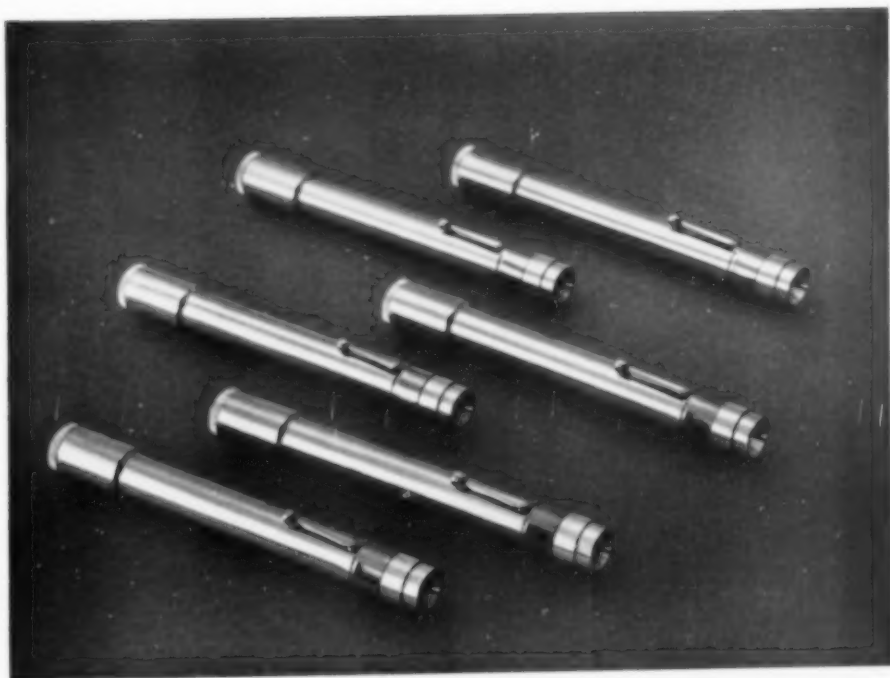


FIG. 1

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Exposure of the instrument to radiation causes the electrical charge to leak away with consequent change of deflection of the quartz fibre needle.

The position of the quartz fibre movement on the scale gives the measure of the dose received.

Quartz fibre dosimeters are very popular as they are designed to be extremely robust and can be read at any time.

In the versions which are now available, the natural leakage (the leakage in absence of radiation) is so low that it is quite permissible to issue them to workers in laboratories fully charged on Monday mornings, and collect them for re-charging at the end of the week.

It will be appreciated that this means that the natural leakage during this period of time has to be insignificant compared with the dosage to be measured.

Dosimeters of this type normally have range, either from 0-200 mr or 0-500 mr, but higher range instruments are available for special operations which have ranges 0-5 r.

The standard type of pocket dosimeter is sensitive to γ -radiation only; it is possible to make thin walled chambers which are sensitive to β -radiation, but these are naturally somewhat fragile. Fortunately, it is sufficient in most cases to monitor γ -radiation; this is because in the majority of cases it is possible to shield the worker from β -radiation, but γ -radiation, being much more penetrating, raises a quite different problem, and it is then necessary to have monitoring apparatus in use to ensure that no one is receiving too heavy a dosage.

Problems also arise with other penetrating radiation, for example with neutrons. Thus, with slow neutrons it is also necessary to provide monitoring equipment to ensure that individuals can measure the extent of their exposure, and, by having knowledge of their exposure, take appropriate action. Dosimeters sensitive to slow or thermal neutrons are similar to those already described and are used in the same way except that the electrode system is coated with a small amount of boron—either natural, or enriched with boron-10.

It is also possible to use quartz fibre dosimeters for monitoring fast neutrons. Unfortunately, it is not easy to obtain the necessary sensitivity to make measurements of the order of the maximum permissible level with a small portable instrument, and few instruments have been produced for this purpose.

As an example of the pocket dosimeter, the C.K. dosimeter made by Cintel-Kershaw (Plate) can be cited. It resembles a fountain pen about 5 in. in length and $\frac{1}{2}$ in. diameter, and has a strong clip enabling it to be carried in the pocket. Two types are available—one capable of indicating a maximum dose of 500 mr and the other 5 r.

HANDLING

It is of prime importance to protect the dosimeter from dampness, especially when the end-cap is removed for charging. Normally this requirement is met by wearing the instrument in indoor clothing due to the drying effect of body warmth. If, however, the dosimeter is worn in an outer garment during inclement weather protection afforded by body warmth will be greatly reduced and detrimental effects of exposure are increased. To avoid deterioration which might possibly result from the continuation of such treatment it is recommended that after excessive exposure

to dampness, the dosimeter be stored with the end-cap removed in an air-tight chamber containing silica-gel. Care should be taken to ensure that no silica-gel dust penetrates the instrument.

It is also recommended that dosimeters which are not in regular use should be stored in a similar manner and kept charged.

The silica-gel should be baked at 110°C for several hours and allowed to cool in an air-tight chamber before the dosimeter is introduced; it will remain active for a considerable period, and may be re-activated when required by baking.

The indicating type which changes colour when re-activation is due is to be preferred.

METHOD OF USE OF DOSIMETER

There are three factors which may affect the accuracy with which small doses can be measured—namely:

1. natural leakage
2. initial setting after charging.
3. variation of temperature.

With regard to natural leakage, this results from a loss of charge by slight leakage through the insulation even in the absence of radiation and precise values are given for respective types of dosimeters.

As the leakage is small, however, it can be ignored when measuring personal dosage at about permissible levels for radiation workers so that the reading obtained will be slightly greater than the true dosage, thus giving a possible margin of safety.

Excessive dosage readings normally indicate considerable exposure to radiation but may alternatively be due to an increase in natural leakage. This can be determined by storing the dosimeter for several days where radiation levels are known to be low, and observing the change in reading—which should not exceed that laid down in the specification.

Since the permissible leakage is small it is necessary to take every precaution to obtain the utmost accuracy when carrying out this test and it is also necessary to test several dosimeters simultaneously, since a low leakage reading on any one instrument is the only guarantee that no unintentional exposure to radiation has occurred.

This last fact illustrates one very important feature of the quartz fibre type of dose measuring instrument, for apart from mechanical damage (due to mishandling), increased natural leakage is the only fault that can seriously affect the dosage reading and it always results in an increase in reading—never a decrease.

It is, therefore, impossible for a quartz-fibre dosimeter to under-estimate the dose received.

Initial setting after charging

The properties of highly insulating materials are such that the apparent leakage is at its greatest after charging. The leakage then diminishes—at first rapidly—and then more slowly—to a final steady value.

For maximum accuracy the dosimeter should be charged some hours prior to use and charging should be carried out as frequently as possible.

Variations in temperature

The position of the fibre is slightly affected by the temperature of the instrument when the reading is taken. A decrease in temperature displaces the fibre across the scale in the same direction as radiation or leakage. In the absence of the two latter factors, the fibre returns to its original value when the original temperature is regained.

The effect is small and may be eliminated entirely by taking all readings at approximately the same temperature, preferably the temperature of use.

The actual specification of the C.K. dosimeters is as follows:

Type	0-0.5 r
Length	4 $\frac{5}{16}$ in. overall
Diameter	$\frac{9}{16}$ in.
Graticule Calibration	0-500 mr in 20 mr steps
Scale	Linear
Calibration Accuracy	± 10 per cent full scale
Natural Leakage	2 per cent maximum per 24 hr
Sensitivity to β -radiation	20 per cent approx.
Type	0-5 r
Length	4 $\frac{3}{8}$ in. overall
Diameter	$\frac{5}{8}$ in.
Graticule Calibration	0-5.0 r in 0.5 r steps
Calibration Accuracy	within ± 0.2 r for dose up to 2 r within ± 10 per cent for doses from 2-4 r within ± 15 per cent for doses from 4-5 r
Calibration Source	The graticule scale is calibrated against a standard radium source
Scale	Linear
Natural Leakage	Within 5 per cent of full scale per 24 hr
Legibility	The scale permits readings to be made to an accuracy of within ± 0.05 r.

Robustness

This dosimeter is capable of withstanding a "drop test", from a height of 1 m on to hard ground without sustaining physical damage, displacement of internal parts, or disturbance or reading beyond ± 20 per cent.

The construction of the dosimeter is such that it is entirely dust and damp-proof when the screwed end cap is correctly in position. It is not expected to be proof against actual immersion in water.

With all these types of instruments "Operating and Servicing Instructions" are supplied with each unit.

Charging units for dosimeters

The type of charging unit supplied for use in conjunction with C.K. dosimeters is of a portable miniature type, and fully transistorized.

It will charge all British makes of dosimeters with centre or off-set electrodes and a simple adaptor is available for modifying the charging chamber to receive dosimeters of smaller diameters (e.g. current American types and some obsolete British and continental types).

Operation of the charger and fine control for zeroing is extremely simple. The illumination of the dosimeter graticule is by means of a built-in lamp and an external light source may be used in an emergency.

No tools are required for replacing either the bulb or batteries and these and all other components are standard items readily obtainable in most countries of the world. The unit is smaller than a packet of 20 cigarettes, and weighs approximately 8 ounces.

DISCUSSION

MR. R. J. SHERWOOD, (A.E.R.E.). Would Mr. Ryder care to comment on the energy dependence of the pocket dosimeter, with special reference to the effects of orientation?

In Mr. Ryder's absence, MR. M. J. HEARD (A.E.R.E.) was invited to comment and said that the quartz fibre electroscope contains an airwall chamber within the outer aluminium casing. The energy dependence is therefore small provided that the radiation is incident normally to the axis. The response (relative to that at 1 MeV) shows a peak of 1.25-1.30 in the region of 70 keV. It falls to 1.0 at 30 keV and drops rapidly at lower energies. The peak is due to increased photo-electric emission from the aluminium central electrode. The energy dependence of the dosimeter is more marked when radiation is incident at small angles to the long axis of the instrument. Under these conditions low energy radiation is attenuated by the metal case, optical components, etc., and the response falls off seriously with energy. (A figure illustrating this is included in the discussion following MR. GARDNER's paper.)

NOTE ADDED IN PRESS

Since the meeting the British Standards Institution has issued British Standard 3385 (1961): specification for direct reading personal dosimeters for X- and γ -radiation.

PERSONNEL DOSIMETRY IN THE PRESENCE OF SOFT RADIATION

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(Received 1 April 1961)

Abstract—The use of the film badge dosimeter, considered as a scientific instrument for the measurement of personal doses of ionizing radiation, is discussed from the point of view of the potential accuracy of the method and its limitations, particularly when used under conditions involving soft X-radiation.

The use of "diagnostic" filters in the badge for the analysis of the incident radiation spectrum is considered essential for high accuracy and the importance of correct calibration conditions is emphasized.

The measurement of β -radiation is briefly considered and the relationship between film blackening and absorbed doses in the organs of the body at risk is discussed from the point of view of reduction of errors.

INTRODUCTION

IN PREPARING this paper, I was reminded that it was almost exactly 20 years ago that I first embarked on the task of setting up a personnel film badge service for a small number of workers in a hospital. The need then was the measurement of personnel doses arising in the use of radium and X-rays for therapeutic purposes, and also softer X-rays used in diagnostic procedures. The film "badge" consisted of a small double-wrapped dental X-ray film around one half of which was folded small pieces of lead foil held in place by a paper clip! This rather crude attempt at providing differential filtration of the incident radiation was reasonably satisfactory. The blackening produced on the half of the film enclosed by the lead foil was assumed to be due to radium γ -radiation whereas the blackening on the half of the film not protected by the foil was taken to be due to both γ - and X-radiation of all qualities.

Today, more suitable emulsions are available for personnel dosimetry than the dental X-ray films previously used and our badges are much more elegant than those used before the war. However, it is somewhat surprising that the badges have remained virtually unchanged in principle for so many years. Until the Radiological Protection Service introduced their improved badge two years ago, little attempt had been made in this country to take advantage of the non-linear response with radiation energy of the photographic emulsion to obtain greater accuracy in personnel dosimetry.

It is often stated that the measurement of personnel doses by means of a film badge may be made with an accuracy of ± 20 per cent. The purpose of this paper is to discuss some of the factors, the variability of which makes this accuracy difficult to achieve, particularly under those conditions when a wide spectrum of radiation

energies is incident on the film, and also to enquire into the assumptions made in relating the blackening produced on an operational film to the actual absorbed dose in those tissues of the body mainly at risk.

ORGANS OF THE BODY AT RISK

The maximum permissible doses recommended by the INTERNATIONAL COMMISSION ON RADIOLOGICAL PROTECTION (1959) have been discussed in an earlier paper in this journal. The parts of the body mainly at risk together with the appropriate maximum permissible doses in any period of 13 weeks (for occupationally exposed personnel) are given in Table 1.

TABLE 1. MAXIMUM PERMISSIBLE DOSES FOR VARIOUS ORGANS OF THE BODY (OCCUPATIONALLY EXPOSED PERSONNEL)

Parts of the body	Max. permissible dose in 13-week period
Whole body, gonads, blood-forming organs, lenses of the eyes	3 rem
Skin, thyroid gland	8 rem
Hands, forearms, feet and ankles	20 rem
Other internal organs (limited exposure)	4 rem

Since the film badge is worn on the upper part of the trunk, it is usually assumed that the personnel film measures the radiation dose absorbed in the skin of the trunk. The doses to other internal organs may be estimated from a knowledge of the skin dose and it is therefore important to establish the validity of this assumption.

RELATIONSHIP BETWEEN FILM BLACKENING AND SKIN DOSE

The blackening produced on a personnel film is usually measured by comparison with control films, taken from the same batch as the operational films, which have been exposed to known doses of radiation of known energy. The control films are normally exposed under conditions such that the blackening produced is almost entirely due to the primary radiation from the calibration source, scattered radiation being avoided as much as possible. The variation in sensitivity of the film with radiation energy is shown in Fig. 1, sensitivity being defined as the reciprocal of the exposure dose in roentgens of radiation of a particular energy which is required to produce the same blackening as one roentgen of radium γ -rays. Thus very large differences of blackening will be produced by an exposure of 1 r as the radiation energy changes. If the film is enclosed in a suitable filter, e.g. 0.6 mm Pb + 0.5 mm Al, it is seen that the sensitivity is reasonably constant down to an energy of approximately 60 keV, but at lower energies the blackening per incident roentgen rapidly falls, until virtually all of the incident radiation is absorbed in the filter.

The absorbed dose measured in rads in the skin, having an average or effective depth of 7 mg/cm² below the surface (REPORT OF I.C.R.P., 1955), is proportional to

the exposure dose in roentgens at the position occupied by the skin. The constant of proportionality depends on a number of factors including the energy of the incident radiation. Although the film absorbs a little energy from the beam in the production of a photographic image, this is usually quite small and for a given radiation energy, the blackening produced is a measure of the exposure dose. Thus if the radiation energy is known, it would appear that blackening produced on a film worn on the surface of the trunk is proportional to the absorbed dose in the skin of the trunk.

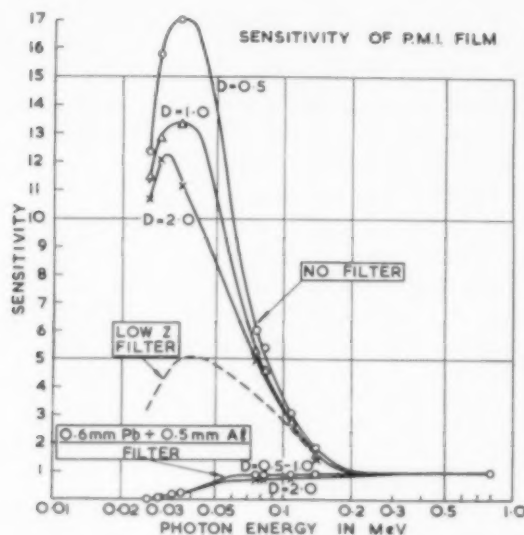


FIG. 1. Variation of sensitivity of Ilford P.M.I film with effective radiation energy. (Data from DOUGAL, 1960.)

However, even if the incident radiation energy is known, which is rarely the case, it must be remembered that the radiation reaching the film is made up of a number of parts. In addition to the primary radiation incident directly on the badge, there is a component of radiation backscattered from the subcutaneous tissues. If the worker is exposed to radiations incident on his body from all directions, there are also components of radiation reaching the film after transmission through various thicknesses of the worker's body tissues. All this additional radiation, other than the primary incident rays, is degraded in energy to an extent depending on the thickness of the tissues underlying the film badge and on the energy of the primary radiation. If the primary radiation is of unknown energy or consists of a wide spectrum of X- and γ -radiation, as all too often occurs in practice, the radiation spectrum reaching the film may be very complex.

Thus it will be seen that the interpretation of the blackening produced on the film in the unfiltered and filtered portions of a badge worn on the trunk is not at all a simple matter as is often supposed. However, although these difficulties have not always been appreciated by those using personnel film badges, it is possible to reduce the errors which have been tolerated previously and to make the film badge

dosimeter a reasonably precise scientific instrument. This may be accomplished by attention to two main aspects of the problem.

REDUCTION OF ERRORS IN FILM BADGE DOSIMETRY

Firstly, by recognition of the existence of these errors and by their subsequent experimental investigation, it is possible to improve the design of the film badge so that an assessment of the accuracy of a dose record may be more easily achieved. The incorporation in the badge of additional filters as described in the paper by JONES (1961) is a step in this direction. The use of a filter of low atomic number, giving rise to the film sensitivity characteristic shown in Fig. 1, enables a reliable estimate to be made of the energy distribution of the radiation incident on the film by the measurement of the ratio of the "apparent doses" giving rise to the blackening in that part of the film under this filter and the blackening produced in the unfiltered area. This ratio varies with radiation energy and the measurement of the former provides a knowledge of the latter.

Secondly, the errors in measurement may be controlled by attention to calibration procedure. If the irradiation of the control films takes place under conditions as similar as possible to those obtaining for the operational films, errors in interpretation of the blackening will be minimized. To illustrate this point, I should like to discuss the effect of backscatter. Fig. 2 shows the variation of the backscatter

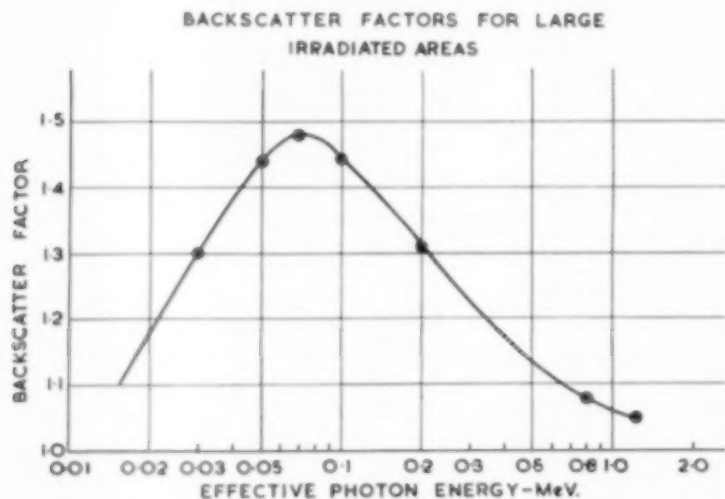


FIG. 2. Backscatter from a tissue phantom as a function of radiation energy.

factor with energy of the incident radiation. The backscatter factor is here defined as the factor by which the exposure dose at a point is increased when a tissue equivalent phantom is brought up behind the point of measurement. It will be seen that the component of the dose measured at the surface of a phantom due to the radiation scattered back from the phantom is small at both high and low radiation energies but reaches nearly 50 per cent of the incident radiation dose at about 70 keV energy.

With the variation of percentage backscatter, we have already seen that there is also an accompanying degradation of energy in the backscattering process. If personnel films are exposed to a source of radiation in the presence of backscatter from a phantom or a human body, the dose evaluated by comparison with control films irradiated only by primary radiation from the source is not the same as that obtained if the control films are irradiated under conditions of full backscatter. The latter procedure gives the true dose with backscatter. Fortunately, the former method generally over-estimates the dose received due to the component of soft backscattered radiation present in the irradiation of the experimental films which is not present in the irradiation of the control films. A safety factor is therefore automatically incorporated. However, this is not universally true as it depends on the energy of the incident primary radiation and, with some films, the magnitude of the exposure dose. Fig. 3 shows the results of exposure of films with and without backscatter for three different primary radiation energies. A comparison of the backscatter factors computed from these results with those given in Fig. 2, which were

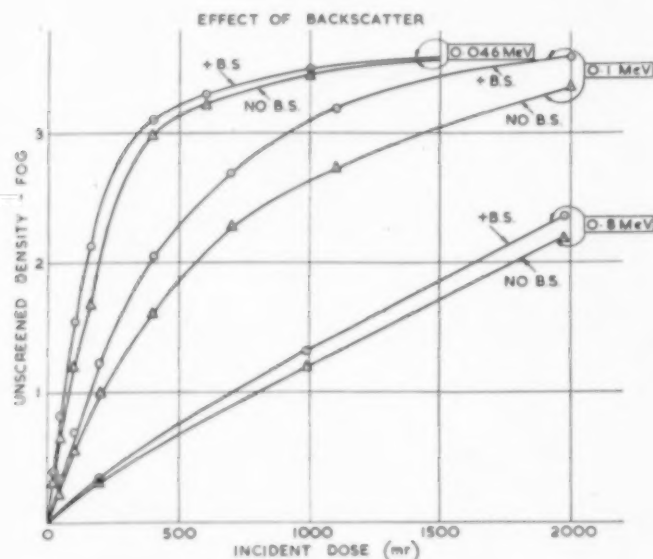


FIG. 3. Relation between film blackening and dose measured with and without backscatter from a phantom.

measured with an energy independent ionization chamber, shows good agreement (± 5 per cent) at 0.8 MeV, fair agreement (± 10 per cent) at 0.1 MeV and poor agreement at 46 keV (± 25 per cent).

To avoid unnecessary errors of this kind, it is advisable to calibrate the control films on the surface of a tissue equivalent phantom preferably using more than one calibration source energy if a wide radiation spectrum is expected operationally. The phantom may be a tank of water or a pile of suitable wax slabs. It often happens, however, that the radiation spectrum obtained operationally is not known with any

precision. In such circumstances, an arbitrary calibration source must be chosen, and the calibration performed with backscatter, the badge including one or more "diagnostic" filters of the kind discussed previously. It is not too much to say that such "diagnostic" filters are essential if the film badge is to become a satisfactory personnel dosimeter for the measurement of radiation having a wide energy spectrum.

DOSE TO BONE AND BLOOD FORMING ORGANS

In order to assess the absorbed dose in bone arising from a given exposure dose it is necessary to make an assumption as to the effective depth of the bone below the skin surface. The 1955 REPORT OF I.C.R.P. suggests that the blood forming organs at risk may be considered at an average depth of 5 cm below the surface of the body. From a knowledge of the skin dose and the effective energy of the incident radiation, it is a simple matter to compute the average depth dose from published depth-dose tables (1961).

Figure 4 shows the relation between percentage depth dose at 5 cm below the skin surface and radiation energy, for the trunk of a person with an effective

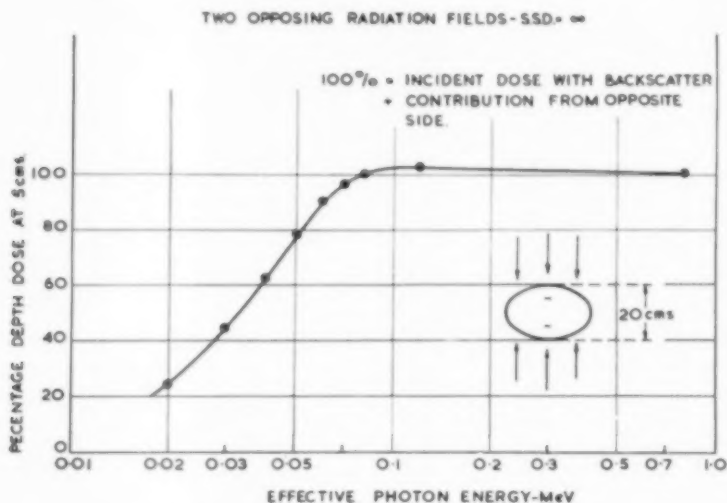


FIG. 4. Percentage depth dose at 5 cm depth as a function of effective radiation energy for two opposed radiation beams.

thickness of 20 cm of soft tissue irradiated by two opposing wide beams of radiation. It is seen that for effective energies greater than about 70 keV, i.e. 200 kVp X-rays with light filtration, the dose at 5 cm depth is approximately the same as the skin dose. However, for soft X-rays normally used in radiography, the film badge overestimates the exposure dose to the blood forming organs by a factor 3 or 4.

In many cases, for example in the preparation and use of radioisotopes, glove box operations and similar procedures, it is known that the radiation is incident almost entirely on the front surface of the body. Under these conditions the film

badge always over-estimates the exposure dose to the bone and blood-forming organs. Nevertheless the absorbed dose in rads to the soft tissue contained in the narrow canals in the bone matrix is higher than would be the case if the whole was soft tissue, particularly for soft radiation. This enhancing effect on the dose level in the soft tissue contained in the bone is shown graphically in Fig. 5 as a function of radiation energy for two different sizes of canals (SPIERS, 1951). It will be seen from a consideration of Fig. 4 and 5 together that for radiation of effective energy in the range 50–70 keV, the absorbed dose in the soft tissue in the Haversian canals may be 2.5 times the dose to the skin.

This effect is very sensitive to the actual diameters of the canals or spaces in the bone. For the bone marrow where the interspaces have an average diameter of $500\ \mu$ (EVE, 1961), the absorbed dose is only about 10 per cent greater than it

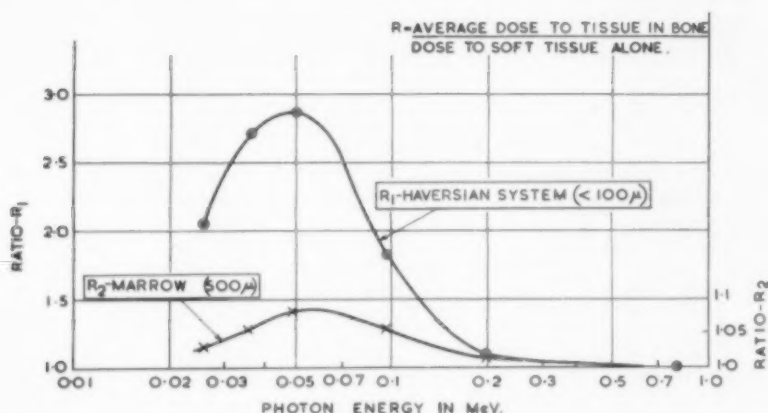


FIG. 5. Dose to soft tissue in bone interspaces related to incident radiation energy for canals of different diameters.

would have been if the whole was soft tissue. In view of this great dependence on the size of the soft tissue interspaces, it will be seen that the dose pattern in and near bone is extremely complex consisting of a mosaic of high and low dose levels throughout the bone structure even when the irradiation exposure is relatively uniform. It is therefore only practicable to prescribe a mean value for the dose to the soft tissues in bone in these circumstances.

I had hoped to extend these remarks to include the complications arising when the film badge is called upon to measure β -rays either separately or in the presence of electro-magnetic radiation. By the use of "diagnostic" filters made of plastic incorporated in the film badge design, it is possible to sort out the proportions of the different types of radiation present in the incident beam. The calibration of the control films with β -radiation introduces greater experimental errors, however, than in the case of X- or γ -rays due to the high absorption of β -rays in the overlying wrapping paper around the film and the greater inaccuracies arising in the β -ray standardization of the calibration source. Fortunately these soft β radiations do not materially affect the dose to the blood forming organs owing to their depth,

although at β -energies greater than about 0.8 MeV (E_{\max}), consideration must be given to the doses to the lenses of the eyes, assumed to be 3 mm deep to the surface of the eyes.

CONCLUSION

To sum up, it is probably true to say that under the simplest conditions of irradiation using near monochromatic radiation, it is possible to evaluate the doses appropriate to personnel film blackenings with an accuracy of ± 20 per cent or even better. For mixed radiations, especially if substantial components of soft X-rays and β -rays are present in the incident beam, the inaccuracies are somewhat greater and for high accuracy the use of "diagnostic" filters in the film badge design becomes a necessity. If, in addition, attention is paid to the most appropriate control film calibration procedure for the operational conditions of personnel irradiation in the Establishment, it is my view that the film dosimeter may be considered a satisfactory scientific instrument for the measurement of personnel doses.

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ASSESSMENT OF THE INTERNAL HAZARD

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Abstract—An assessment of the risks from internally deposited radioactive materials requires a knowledge of the dose received by individual organs of the body and of the dose response relationship for the tissues in question. The paper reviews the present position regarding the basis for fixing maximum permissible levels of internal contamination and discusses the parameters which are required for the calculation of dose. Suggestions are made for improving monitoring procedures so that the maximum information may be obtained about the risk to which persons are exposed when working in a radioactive environment.

INTRODUCTION

THE PRESENT position with regard to making an assessment of the risk from internally deposited radioactive materials is probably less satisfactory than that of assessing the hazard from external radiation. Only in the case of radium is there a considerable amount of information on the effects of prolonged exposure of the body to small amounts of radioactive material. There is however a considerable amount of information, from observations on persons working with X-rays and radium as well as on persons treated with ionizing radiations for various diseases, about the effects of external radiation on body tissues. In the light of this experience it has been agreed that certain radiation doses delivered to the body and its organs over specified periods of time might be accepted without appreciable effects being manifest in the individual receiving them.

Again, by comparison with the doses received from natural sources, principally from local γ -rays, cosmic rays and the naturally occurring isotope of potassium, ^{40}K , in the body, certain doses averaged over the whole population are considered to be acceptable with regard to any increased risk of genetic damage (H.M.S.O., 1960). What has been done in assessing the internal hazard is to assume that these limits on dose are equally applicable to irradiation from the exterior or from radioactive materials within the body. There remain the problems of assessing the effect of varying the volume of the irradiated tissues both on the macroscopic and microscopic scales, of the transmutation of the elements deposited within the irradiated tissues and, in common with the assessment of the external risk, the effects of dose rate and irradiation time on the dose response relationship. Furthermore, having accepted these limits on dose we still require a knowledge of the metabolism of the chemical elements concerned before we can calculate permissible levels of body radioactivity or of the radioactive contamination of the air we breathe and the water and food we ingest.

The most comprehensive account of these matters is to be found in the REPORT OF COMMITTEE II OF THE INTERNATIONAL COMMISSION ON RADIOLOGICAL PROTECTION

(I.C.R.P.). It is the purpose of this article to summarize this information, and also to comment on the measures which might be taken to ensure the adequate control of body radioactivity.

THE BEHAVIOUR OF RADIOACTIVE MATERIALS IN THE BODY

Radioactive materials may enter the body in three possible ways, by inhalation, by ingestion or by penetration of the skin. The latter constitutes direct entry into the blood stream from whence the material will be offered to the various organs and parts of the body, to be retained there for various periods of time before being excreted principally in the urine and faeces but also in sweat and breath. The dose each organ receives depends markedly on this residence time, it will also depend upon the rate at which the radioactive material enters the organ, although if uptake into the organ occurs very rapidly, the rate will only be of importance if the radioactive half-life is comparatively short. Our monitoring services should therefore be equipped with the appropriate apparatus for assessing the degree of contamination in wounds and its rate of removal into the blood stream so that appropriate advice can be given with regard to the advisability of surgical interference.

Entry by inhalation or ingestion gives rise to a far more complicated procedure and the fraction entering the blood by these routes depends in a complex manner on the physical nature of the particle as well as upon its metabolic behaviour.

Of any very soluble vapour which is inhaled, a small part is immediately exhaled. The greater part rapidly enters the blood stream following its solution in body fluids. The deposition of particulate matter in the different parts of the respiratory system is more complicated. It is assumed to proceed via four different physical phenomena: inertia, sedimentation, wall effect and Brownian motion (HULTQVIST, 1956). So the shape, weight, size and nature of the particles are important. The removal of particles from the lung and airways depends amongst other processes on physiological solution in body fluids, on phagocytic action after which they will usually be found in the hilar lymph nodes where they will remain for very long periods of time and on ciliary action in the upper airways as a result of which they will be slowly moved out of the system to be expectorated and swallowed. It is worth noting therefore that following the inhalation of radioactive materials, the gastrointestinal tract might be irradiated, and in fact, it is the irradiation of this part of the body which limits the inhalation of many insoluble radioactive materials. The radiation dose received by the various sites along the routes of entry depends markedly on the residence time of the radioactive material at these sites. In the case of inhalation this will clearly depend upon the site of deposition since this determines the processes of removal. There is also some evidence that it may depend upon the concentration of dust in the inhaled air; a greater concentration increasing the rate of removal, presumably by increased stimulation of phagocytosis (LA BELLE and BRIEGER 1959). Ideally, therefore, the monitoring of airborne radioactivity should include measurements of all the parameters I have mentioned if we are to make a proper assessment of the risk to which persons breathing the contaminated atmosphere are exposed.

Following ingestion, materials remain in the different sections of the gastrointestinal tract for different times depending on the way in which they are transferred across the gut wall and on the time taken for the main bulk of ingested

material to traverse that particular section of the tract. Those materials which are able to enter the bloodstream irradiate the stomach and parts of the small intestine only. The remainder travel on irradiating the large intestine and sometimes being reinforced by additional material which, having entered the blood stream, has been re-excreted into the gut. It may be important, therefore, in assessing the risk from ingestion as a result of surface contamination, to examine the nature of the contaminant in addition to measuring its radioactivity.

Ideally we would like to have information about the behaviour of radioactive materials in the different organs of the body from studies based on humans who had been exposed to the appropriate materials under the expected conditions of exposure. Apart from the ethical considerations which might preclude any experiments of this type there are other intrinsic difficulties, not the least of which is the fact that to establish the appropriate parameters for occupationally exposed persons, these experiments would need to be carried out over periods which might be equal to the working life time of the individual. Human data are therefore scarce and only in the case of radium have we an accumulation of human experience extending over a lifetime. In a few cases radionuclides have been administered to humans therapeutically or for medical diagnosis, sometimes to determine the metabolic behaviour of an element or compound. In some cases accidents have occurred in which radionuclides have been taken into the body. Every additional case contributes to our knowledge of these matters and we should lose no opportunity of increasing that knowledge by making the fullest investigation in all cases of accidental exposure.

For the majority of radionuclides the only available data comes from animal experiments. Sometimes even this is lacking so that we are then forced to rely on estimates made from a comparison with elements having similar chemical behaviour. There is, however, a considerable amount of information about the behaviour of stable elements in the human body following their intake in food. Recent studies of the concentrations of trace and minor stable element distributions in the human body and in food have been particularly helpful in this respect but much still remains to be done.

The excretion of an element from the body may follow a very simple pattern described by a single exponential law. In other words, the amount of material excreted daily is a constant fraction of the retained burden. This fraction is analogous to the radioactive decay constant of a radionuclide and it is possible to speak in terms of an effective constant of elimination from the body which is the sum of the two constants.

In many instances however, particularly those materials which have a long residence in the body and also have long radioactive half periods, for example the bone seeking isotopes, radium-226 and plutonium-239, the excretion pattern may be very complex, probably a series of exponential terms. Such series are not simple to handle mathematically and, for convenience in making estimates of dose, but certainly not because it has any obvious biological meaning, a power function of time is used to describe the excretion pattern (LANGHAM, 1957; NORRIS *et al.*, 1958; SANDERS, 1960). In such cases the retained fraction is proportional to a negative power of the time which has elapsed since the radioactive material entered the body and the fraction of the retained burden which is excreted daily therefore varies inversely with the time since the burden was acquired. In the I.C.R.P. recommendations

the maximum permissible concentrations of radionuclides in air or in water are all calculated on the assumption that excretion from the body or from any one of its organs may be expressed by one exponential term. However, in an appendix to the recommendations the values of the maximum permissible concentrations in air and in water for certain bone seeking radionuclides are also calculated assuming that their excretion from the body follows a power function of time. It is worth noting that the power law calculation increases the permissible daily intake of radium-226 and strontium-90 by about a factor 10 above that obtained from the calculation which assumes that excretion of the materials follows a simple exponential law.

CONTROL OF RADIOACTIVE MATERIALS WITHIN THE BODY

At the present time it is necessary to assume that for most radioactive materials in the body their removal cannot be accelerated beyond the rate governed by the normal metabolic processes, without involving the individual in more serious dangers. There are exceptions, for example, local contamination of the skin or in a wound may often be removed by washing, sometimes with chemical solutions, or by simple surgical excision. I have previously referred to the fact that increasing the concentration of inactive dust in the atmosphere may tend to increase the rate of elimination of radioactive particles from the lung. It is possible that future research may also provide suitable materials which will increase the removal of radioactive materials from other parts of the body. Some progress has already been made in this direction. For example certain radioactive metals which are concentrated in bone and very firmly fixed in the skeleton may be partially removed by the administration of chelating agents. However these agents are often highly toxic materials themselves so that they must be administered with care and so far their efficiency is disappointingly small.

There are instances also where the uptake of radioactive materials into the appropriate body organ may be reduced. For example, reduction of the uptake of radioiodine into the thyroid by the concurrent administration of inactive iodide is well known. This aspect of protection from radioactive materials by the daily administration of an appropriate inactive carrier is perhaps worthy of further study. However, it is not possible in every case to prevent the uptake of radioactive materials in this way. No stable isotope exists for some radio elements and in others it might be dangerous, because of chemical toxicity, to administer the appropriate stable material. Our principal aim, therefore, must be to keep the intake of radioactive material within the recommended limits by suitable design of the installation, by control of the working methods and by carefully monitoring the radioactivity of the environment, that is of surfaces, hands and clothing and in the atmosphere.

As an additional precaution, and to check on the assumptions made when setting the permissible limits for the radioactivity of the environment, the radioactivity of the body should also be measured. Many of the assumptions made concerning the relationship which exists between surface or air contamination and the amount of material in the body of a person working in the contaminated area have undoubtedly tended to be pessimistic in the interests of safety.

Clearly, in the interests of economy, it is just as undesirable to set our maximum permissible levels of contamination too low, as it is, in the interests of safety, to

set them too high. For these reasons it will be necessary for some time to come, to make regular measurements of body radioactivity on a large and representative sample of people working with radioactive materials concurrently with observations on the radioactivity of the environment in which they work. In fact, apart from this aspect, there is another reason why we should consider the advisability of making regular measurements of body radioactivity in addition to those which are customarily made when exceptional exposure has been suspected. Current recommendations are expressed in terms of the total dose received by various organs and parts of the body, that is the internal and external doses should be summated. If there is an appreciable internal dose it may be necessary to restrict the external dose. Furthermore, since it is now regarded as necessary to keep records of accumulated dose, the presence in the body of radioactive materials of appreciable effective half-life prejudices the future capacity of a person to receive additional radiation from either internal or external sources and thus might affect his career.

There are two possible ways of measuring body radioactivity; directly, by *in vivo* observations, or indirectly, by a measurement of excreted urine and faeces and in the special cases of radium and thorium, of radon and thoron in the breath. Direct observations using a detecting instrument exterior to the body are possible only when the radioisotope concerned emits radiations of sufficient energy to penetrate the overlying tissues. Such observations are usually limited, therefore, to measurements of γ -emitting isotopes, including the special case of the positron emitters, which produce 0.51 MeV γ -rays by annihilation processes within the body. With a very much diminished sensitivity per μc the method may be used also for the measurement of β -emitters, provided that the bremsstrahlung produced by deceleration of β -rays in the body tissues, is sufficiently energetic to escape from the body surface in measurable quantities. The development of scintillation counters of very high intrinsic efficiency for the detection and identification of γ -rays (SPIERS and BURCH, 1957) and the construction of low background laboratories large enough to house the whole human body (MILLER *et al.*, 1956; VENNART, 1960) have been important features in the development of our radiological protection services.

With such equipment it is possible to estimate very low levels of body radioactivity such as that due to ^{40}K , a naturally occurring isotope of potassium. In this way the amount of body potassium, about 150 g, may readily be measured with an error of a few per cent. Very small amounts (about 5–10 μc) of caesium-137 from nuclear test explosions, which are now present in all human beings may, also be detected and measured in modern body monitors with an error of about 1 μc (LANGHAM and ANDERSON, 1959; MAYCOCK *et al.*, 1960). It is worth noting however that equipment with such high sensitivity is not always essential for routine protection work. For many isotopes the maximum permissible body burden is several microcuries and routine measurements of the type I have advocated could in such cases be made with very simple apparatus. Furthermore, since little or no shielding material would be required, the apparatus could be moved from place to place in order to facilitate the more rapid examination of the staff concerned.

However, for radionuclides which emit only α -rays or very weak β - or γ -rays, indirect observations on excreta are all that can be undertaken. The interpretation of these measurements is difficult since, as mentioned above, in many instances we do not know the precise relationship between the amount excreted and the retained

burden. In particular, for certain isotopes the fraction of the retained body burden which is excreted daily may change with the time since the material was taken into the body. In such cases, for a proper assessment of the body burden, the whole history of the intake of the material must be known. The only certain way to obtain this information is to make regular measurements.

There are a number of practical difficulties associated with excretion studies. It is difficult enough to ensure complete collection of urine and sometimes quite impossible to obtain a representative faecal sample. All too often the relationship between faecal and urine excretion is unknown. Sometimes, however, the relationship between the daily excretion and the retained burden may be obtained from experiments using an isotope of the material which may be detected in the whole body counter. For example, the γ -emitter strontium-85 may be used to yield information about the purely β -emitting strontium-90. Furthermore, as the sensitivity of whole body counters improves, many more isotopes might be measured by the direct technique, i.e. by *in vivo* counting. For example, a maximum permissible lung burden of the predominantly α -emitting element uranium can now be measured directly with a sodium iodide crystal scintillator by virtue of the very weak γ -rays that are also emitted (COFIELD, 1960). There is a possibility too that the α -emitter plutonium might be measured directly because it emits a 17 keV X-ray in about 4 per cent of its disintegration.

It is not intended to imply, however, that the ultimate aim is to measure all radioisotopes in the body by direct *in vivo* counting. In order to reach a reasonable accuracy the time for a measurement is often prolonged because of the very low counting rates involved. Furthermore, if repeated measurements are required it would prove to be very tedious for the individual concerned. The measurement of excretion on the other hand involves very little inconvenience for the person undergoing the test and the subsequent measurements may be made at any convenient time and in a laboratory that is remote from the person concerned. This would be a very important advantage in the organization of a national service to carry out such work.

Both types of measurements can clearly play a part in improving our knowledge about the behaviour of radioactive materials in the body and for this reason both should be employed whenever the opportunity is offered. Concurrent with such measurements more precise information should be obtained about the risk to which these measured individuals have been exposed. This suggests more research in the field of environmental monitoring to ascertain the conditions giving rise to the uptake, the physico-chemical nature of the radioactive materials involved and the fraction of the radioactive material in the environment that has entered the body.

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THE EXTERNAL HAZARD FROM EQUIPMENT GENERATING X-RAYS

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X-RAYS are electromagnetic radiation like light and radio waves. They have wavelengths which are shorter than either of these, and which lie generally in the band from 1 \AA to 10^{-3} \AA (10^{-8} cm to 10^{-11} cm) corresponding to energies of about 10 keV to 10 MeV, though they can, of course, be generated at energies both above and below this range. They differ from γ -rays only in the mode of production, γ -rays being produced by changes in the nucleus of an atom whereas X-rays are produced outside the nucleus.

X-rays can have a line spectrum, like γ -rays, when caused by radioactive decay or they can have a continuous spectrum, like white light, with a line spectrum superimposed upon it. The line spectrum is characteristic of the atom producing it, and is called the Characteristic X-ray. The continuous spectrum is called either White Radiation (by analogy with white light) or Bremsstrahlung (from the German "braking radiation", because it is produced by the sudden stopping or braking of the electron).

X-rays are usually produced by accelerating electrons in an evacuated space, and allowing them to strike a target. Occasionally, for some special purpose, an X-ray source may be made in which β -particles from a suitable radioactive material impinge on a target.

Either of these ways of producing X-rays may operate unintentionally, and it is important that these possibilities should be realized. Any thermionic valve which operates at more than a few kilovolts may emit a substantial intensity of X-rays. In certain cases this happens as a result of improper adjustment, but in many cases it occurs under normal operating conditions and suitable shielding has to be provided.

Similarly with any β -active source, the stopping of the β -particles will give rise to X-rays. The efficiency of production of these bremsstrahlung is proportional to the atomic number of the target material, and is thus very much greater for the heavy metals than for such materials as paper, wood and plastics. In the laboratory it is convenient to provide stands made of transparent plastic for holding test-tubes, bottles and the like which contain β -emitting material. For storage and transport of such materials, containers have an inner lining of low atomic number material to absorb the β -radiation and this may then have to be surrounded by an outer layer of lead or other high atomic number material, to absorb the bremsstrahlung. In all cases the thickness of the low-atomic number material should be at least as great as the maximum range of the β -particles.

The most important sources of X-rays are high-voltage equipment which is either specifically designed to produce them or does so as an incidental by-product of its operation. The output from an X-ray set is usually quoted in r/min/mA at 1 m, and it depends very much on the tube voltage and on the filtration which is in the beam.

Typical figures which will give some idea of the intensities, are as follows.

Operating Voltage	Output	Operating Current	Dose rate at 1 metre
50 kV	0.3 r/min per mA at 1 m	10 mA	3 r/min
200 kV	3.0 r/min per mA at 1 m	5 mA	15 r/min
1000 kV	33 r/min per mA at 1 m	3 mA	100 r/min

It will be seen that the dose-rates in the beam are very large; even at moderate energies the 3 month dose for an occupational worker is received in one minute at 1 m from the source. In medical diagnostic radiography the exposure times are extremely short, and except for such purposes it is most important that no part of the body should ever be exposed to the direct beam. Particular care is necessary with crystallographic X-ray equipment so as to avoid fingers getting into the beam whilst making adjustments; at the short distances involved the dose-rate may well be in the region of 1000 r/min. Most manufacturers nowadays fit devices intended to prevent this, but people are very ingenious in circumventing such things and may not realize the dangers this can lead to.

Most of the industrial and medical X-ray equipment being marketed today is self-protected in directions outside the useful beam and this protection is usually sufficient to reduce the intensity at 1 m to between 100 mr/hr and 1 r/hr depending on the type of equipment.

In most cases where the X-ray production is unintentional or incidental to the operation of equipment the intensities are likely to be much smaller, but if the hazard is not properly understood the danger may in fact be greater.

In monitoring areas around X-ray equipment there are certain special aspects which must be borne in mind:

- (i) The energy of the radiation. This may be lower or higher than the normal range of sensibly uniform response of a survey instrument or personal dosimeter.
- (ii) The output may be pulsed instead of relatively constant. This occurs to some extent with low and medium voltage equipment and is usually marked in high energy equipment, in some cases the pulse duration is only 1 μ sec or even less.
- (iii) The direction of the useful beam is generally not fixed. It may often be variable over a very wide range of angles and source position.

In the choice of survey instruments the ionization chamber is generally best. Geiger counters have usually a poor energy response and are affected by the pulsating nature of the source. Scintillation counters using suitable plastic phosphors are better than Geiger counters from both aspects but may still fail where pulse durations are very short.

The ionization instrument must be properly constructed for the particular application and care is necessary to select the appropriate instrument. For low energies a thin wall is required to avoid undue attenuation of the radiation, and the walls and all parts which penetrate the walls into the interior of the chamber must be of the low atomic number materials to avoid photoelectric emission. For high energies the wall must be of sufficient thickness to give its full contribution to the ionization. Where the source is pulsating, the collecting voltage on the chamber must be adequate to give saturation conditions under the instantaneous intensity conditions—which may be very much more onerous than suggested by the mean intensity indicated.

Film badges are of great value in giving an integrated dose and are free from difficulties arising from pulse duration, since so far as is known there is no reciprocity failure in the response to X-rays. Their energy response at low and high energies which gives rise to some difficulties is fully dealt with in another paper in this journal.

THE EXTERNAL HAZARD FROM β AND γ RADIATION SOURCES

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Abstract—The paper commences with summaries of the units of radiation dose and of the maximum permissible levels for occupational exposure. The choice of techniques and equipment are described and some of the factors governing such choices are outlined and mention is made of measurements for hazard assessment. The desirable characteristics of survey meters are also discussed, together with some examples of equipment currently available.

1. UNITS OF RADIATION DOSE

THERE are three units of radiation dose in use today.

The röntgen is a unit of X- or γ -rays, emitted from a source, such that ions carrying 1 e.s.u. of quantity of electricity of either sign are produced from irradiation of 1 cm³ of air at S.T.P. (2×10^9 ion pairs are produced in 1 cm³ of irradiated air). It is equivalent to an energy absorption of 96.5 ergs/g of soft body tissue (I.C.R.U. 1956).

The rad corresponds to an energy absorption of any ionizing radiation of 100 ergs/g in any chosen medium.

The rem corresponds to the dose in tissue, which results in biological damage equivalent to that produced by 1 rad of 200 kV X-radiation. In fact the dose in rem is the dose in rads multiplied by the relative biological effectiveness (R.B.E.).

For β -, γ - and X-radiation, the R.B.E. may be taken as unity. So, when monitoring for β - or γ -radiation, these units may be considered identical.

2. MAXIMUM PERMISSIBLE LEVELS OF RADIATION

The maximum permissible levels of radiation applied in the U.K.A.E.A. are those given in the recommendations of the INTERNATIONAL COMMISSION ON RADIOLOGICAL PROTECTION, adopted in September 1958 (and amendments) (I.C.R.P. 1958 and I.C.R.P./59/17) and since generally accepted by the Medical Research Council Committee on Protection against Ionizing Radiations. The principal figures for occupational exposure are:

Whole body, blood forming organs and lens of eye	Hands, forearms, feet and ankles	Skin, thyroid and bone
Total dose of 5 (age—18) rems implying 5 rems/year	75 rems/year	30 rems/year
3 rems/13 weeks which is equivalent to: 0.23 rems/week 6.0 mrems/hr	20 rems/13 weeks which is equivalent to: 1.5 rems/week 37.5 mrems/hr	8 rems/13 weeks which is equivalent to: 0.6 rems/week 15 mrems/hr

For work near to a bare source, where the beta dose is high, the dose to skin could be the limiting factor.

These figures have been chosen so that, in the light of present knowledge, doses when accumulated over a long period of time, or resulting from a single exposure, carry a negligible probability of severe somatic, or genetic, injuries.

While the policy must be to minimize radiation exposure, in certain circumstances workers may exceed their average weekly permissible dose, but only under emergency conditions may the 13 week permissible dose be exceeded.

At present, no upper limit to radiation dose rate has been laid down, provided maximum permissible levels for integrated dose are not exceeded.

3. THE CHOICE OF TECHNIQUES AND EQUIPMENT

The first stage in the successful control of external radiation is the choice of suitable techniques, facilities and monitoring equipment (DUNSTER, 1954). The following points must be considered:

- (1) How weak a source of radiation will be sufficient?
- (2) How closely will personnel have to approach the source?
- (3) Dose rates at working positions.
- (4) How frequently and for how long will operators be exposed?
- (5) If shielding is necessary how best can it be fitted?
- (6) Instructions to avoid accidents and to deal with emergencies.

The answers to these questions will vary according to the nature of the work being planned; therefore each case should be treated individually. However, one important general principle is that sources should never be picked up with bare or gloved hands. For example the γ dose rate from 1 mc of radium at a distance of $\frac{1}{16}$ in. is the same as that from 10 c at 1 ft (84 r/hr). For 1 mc of a β -emitting source the dose rate could be as high as 3000 rads/hr at a distance of $\frac{1}{16}$ in.

The dose rates at working positions may be measured during operations, but it is advisable to make preliminary estimates before active work commences. This presupposes some knowledge of the type of source to be manipulated such as isotopic composition, strength, physical form and the proportion of total radiation (β - plus γ -) that is of a penetrating nature (γ). This latter factor could be important when assessing the limiting hazard from a bare source. For instance, at a distance of 6 in., the β - plus γ -: γ - ratio of radiation from a bare source of old fission products may be as high as 50:1, in which case the less penetrating (soft) radiation component is the limiting hazard.

When estimating dose rates, most configurations may be dealt with by using several simple formulae (A.E.R.E.-L. 101, 1959). Although only approximate, the answers are usually within a factor of 2, or 3, of the measured dose rate.

By definition, a point source is one whose physical size is small compared with the range of the emitted radiation in that substance and with the distance between the source and the detector. In practice, the distance between the source and the detector should be at least 5 times the maximum dimension of the source (APPLETON and KRISHNAMOORTHY, 1960).

For such a point source of β -radiation (neglecting air and self absorption) of strength C curies, the dose rate at 1 ft is given by:

$$R = 300 C \text{ rads/hr.}$$

This formula is valid for β particles of maximum energy greater than 0.5 MeV. In practice, the equation usually overestimates the dose rate as true point sources (having negligible self absorption) of β -radiation are extremely rare.

For a point source of γ -radiation of strength C curies and emitting 1 γ -photon of energy E MeV/disintegration, the dose rate at 1 ft is given by:

$$R = 6 CE \text{ rads/hr.}$$

At d feet the dose rate becomes:

$$R = \frac{6CE}{d^2} \text{ rads/hr.}$$

These formulae are valid for γ -radiation of energy 0.3 MeV to 3 MeV.

By definition, an infinite volume source is one whose dimensions are very large compared with the range of the emitted radiation in that substance. At the surface of such a source (known as the semi-infinite volume case) of specific activity $S \mu\text{c/g}$ of mean radiation energy E MeV the dose rate is given by:

$$R = 1.07 SE \text{ rads/hr.}$$

This formula may be used to obtain the dose rate at the surface of large sources such as a tank of radioactive liquid and is particularly applicable to beta sources, especially solutions as volumes of a few ml. can be considered as infinite.

If the dose rate at a distance from the source is required the equation becomes:

$$R = \frac{1.07 SE\Omega}{2\pi} \text{ rads/hr}$$

where Ω is the solid angle subtended at that point by the source.

Occasionally, when large sources of β -radiation are manipulated, significant doses from bremsstrahlung may also be encountered. Bremsstrahlung, a form of electromagnetic radiation, are emitted when electrons (or other charged particles) are decelerated in material. The energy of emitted photons is in the form of a continuous spectrum (the upper limit being the maximum energy of the incident electrons) and is proportional to the square of the atomic number of the material in which deceleration occurs.

In practice, bremsstrahlung may be a hazard in cases of large sources of pure β -emitters; for example 10 c of P^{32} solution in a glass bottle whose walls are thick enough to stop most of the β -particles gives about 1 rad/hr of bremsstrahlung at 4 in. Such radiation can be minimized by shielding with some material of low atomic number.

4. ASSESSMENT OF THE HAZARD

To assess the hazard it is necessary to decide what measurements to take and why they are required:

- (1) To measure the dose rate at working positions and hence calculate the safe working time. Note that with bare sources or contamination at close range

β -radiation may be the limiting hazard. With shielded sources the limiting hazard is γ -radiation.

- (2) To measure the dose rate at various points for information on probable hazard from future sources of that type.
- (3) To demonstrate for record purposes that conditions in the area are safe. The monitoring of shielded facilities for weaknesses, during commissioning trials, is a typical case.
- (4) If abnormal conditions arise (possibly due to an accident) to trace possible radiation sources or faults in shielding.

5. MEANS OF DETECTION AND MEASUREMENT

As radiation cannot be detected directly by any of the senses, instruments must be used instead. Most instruments are designed to detect, measure, or identify radiation. In general, the survey meters used in radioactive areas for measuring dose rate are only of limited value for identifying the nature of radiation. It is only possible to distinguish between β - and γ -radiation and to make a crude estimate of γ -energy. Although it has not been possible, hitherto, to make spectrometric analyses in the field, portable spectrometers are now becoming available, but their use is too specialized to be considered in this paper. For these reasons, the paper is restricted to instruments for the detection and measurement of radiation.

(a) Films

Many aspects of dosimetry using film badges are discussed in detail in another paper. The chief use of the film is, of course, for personal dosimetry. It may also be used for reasonably accurate measurement of the surface dose rate from a source by placing it in contact for a convenient period of time. For this purpose, it is superior to other detectors as it can be calibrated accurately, can be bent to follow the contours of a source and can be placed in close contact with its surface.

(b) Dosimeters

Many types of dosimeter have been produced, mostly using an ion chamber as the detector. In the past, portable integrating ion chambers have been used to measure the dose in laboratories, but fell into disuse at A.E.R.E. when pocket dosimeters became available. The latter are of the quartz fibre direct reading type and, although not as accurate as a film badge, they have one great advantage in that they can be read directly. For this reason, it is advisable for staff, working in areas where over-exposure to γ -radiation could readily occur, to wear both films and pocket dosimeters. Other dosimeters are available, which give an audible warning when a preset integrated dose, or dose rate, is exceeded.

Both film badges and dosimeters may be used for timed exposures to determine dose rates in areas which are inaccessible to survey meters.

(c) Survey meters using ion chambers

There are two basic classes of survey meter, hand held and the so called "hot spot". In the "hot spot" class the ion chamber is separated from the amplifier and meter by a long rod or flexible lead. This allows the operator to make measurements of high dose rates, while remaining in an area of much lower dose rate himself, hence

minimizing the dose received during the operation. A simplified circuit diagram of a typical survey meter is shown in Fig. 1. As ionization, due to incident radiation, takes place in the chamber, a small current flows through the resistance (R). This causes a slight change in the voltage of the grid of the electrometer valve. Hence a larger current flows in the meter circuit. A typical ion chamber volume is 1000 cm^3 . The resistance (R) is varied when range is changed, but a typical value on the lowest range is $10^{11} \Omega$. At a dose rate of 7.5 mrad/hr a current of about 10^{-12} amp would pass.

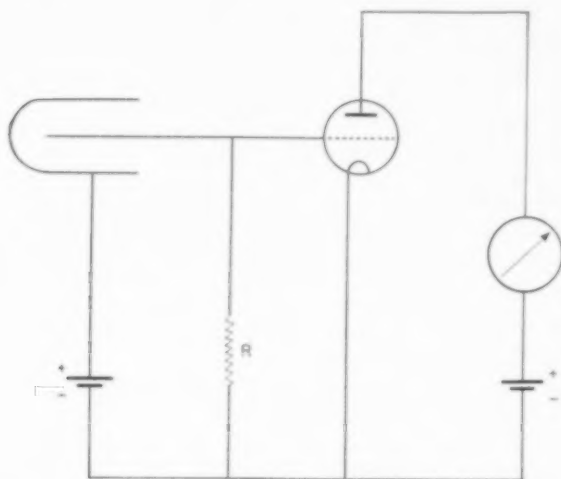


FIG. 1. A simplified circuit diagram of a typical survey meter, using an ion chamber as the detector.

The desirable characteristics of such an instrument are:

- (1) A suitable compromise between light weight, reliability and robustness is required. On a "hot spot", (see Figs. 2 and 3) the extension rods between amplifier and probe must have positive connexions to avoid piezo-electric effects, which could swamp the meter on movement of the monitor.
- (2) Simplicity of operation is essential. Portable instruments should be self contained and hence should be powered by batteries, which could possibly be recharged using a mains operated plinth system. The zero control and other switches must be positive, so that they cannot be knocked accidentally.
- (3) It is highly desirable that the instrument should fail safe by automatically indicating its unserviceability. It is not always possible to arrange this, therefore, to enable the monitor to be checked while in operational use, it is essential to have a switch, giving battery test and set zero positions, and a small calibration source incorporated in the instrument.
- (4) Clarity of display. One well known field ratemeter (see Fig. 4) has the meter mounted on top of the box, with three scales marked (see Fig. 5), but the range switch, at the side, has five positions. This system is far from

satisfactory. Meters should have either a large logarithmic sweep scale (see Fig. 6), or a medium sized linear one with the range switch altering the figures (see Figs. 7 and 8). If the monitor is to be used out of doors an illuminated meter is a great asset.

- (5) The speed of response of a monitor is governed by the ion chamber volume, circuit capacity and instrument amplification. Circuit capacity in the long leads of a hot spot can cause difficulty and with all survey instruments some compromise must be made between accuracy and response time. The specified accuracy of the instrument should also be known. (A typical design tolerance is that the instrument should indicate 100 ± 10 per cent of the true dose rate at full scale deflection.)
- (6) It must be quick and simple to maintain and repair.
- (7) Finally, it must be easy to decontaminate.

When monitoring for β -radiation it should be borne in mind that, due to the directional properties of the window and its finite thickness to β -particles, the scale reading is only an indication of dose rate and not an accurate measurement.

(d) *Other survey meters*

Most survey meters incorporate ion chambers, but with the electronics systems at present available it is not possible to measure down to natural background levels without the instrument becoming too bulky for operational use. Although new developments show promise that this may shortly be possible, it is a common practice, at present, to use counting type instruments, of the field ratemeter type, incorporating either geiger tubes (see Fig. 4) or a scintillator and photomultiplier system.

Scintillators in current use are γ -sensitive only. For accuracy, it is essential to know the γ -energy of the incident photons and the γ -energy at which a geiger instrument has been calibrated to read mrad/hr; then correction factors can be applied. The ion chamber is the least γ -energy dependent detector (see Fig. 9). Whatever equipment is used operators are advised to know the γ -energy response. A common type of ion chamber survey meter has been found to indicate only a quarter of the true dose rate at unusually low γ -energies (about 40 keV), although accurate at higher ones.

Most of the desirable characteristics listed for the ion chamber type instruments are applicable to the geiger and scintillator types. In the past an inherent weakness of counting type equipment has been its failure to maintain full scale reading at high dose rates. This dangerous characteristic is on the way to being overcome.

(e) *Other useful instruments*

The side window type geiger tube of a contamination monitor may be used to locate precisely narrow beams of radiation. (It should be borne in mind that the detector (ion chamber or geiger tube) averages the dose rate over the whole of the sensitive volume, thus the dose rate in a pencil beam would be underestimated.) The response varies according to γ -energy. Typical results with a B.12 type glass-wall side-window geiger tube are as follows.

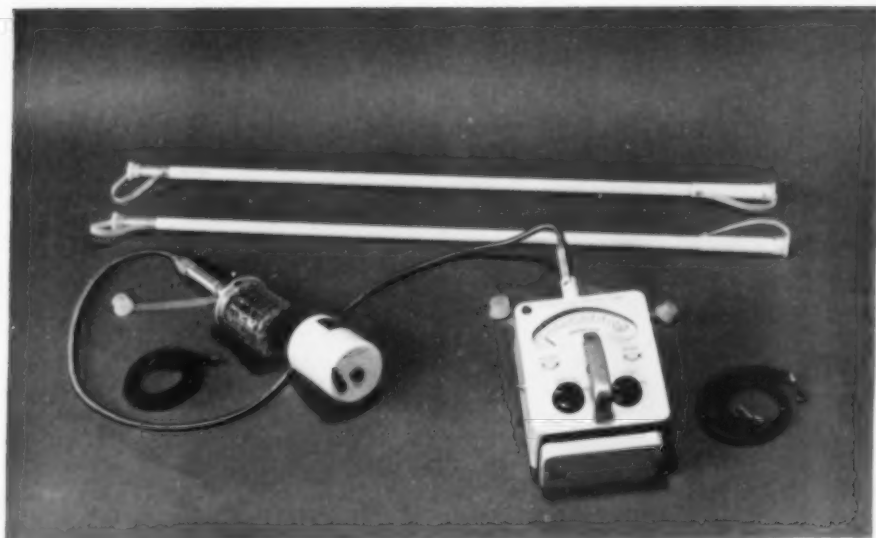


Fig. 2. A "hot spot" survey meter, showing the extension rods, β - γ -sensitive ion chamber and detachable β -shield, which also contains a beta calibrating source. This monitor will measure dose rates of up to 100 r/hr.



FIG. 3. A "hot spot" survey meter in use in an active area.

[facing p 142]



FIG. 4. A field ratemeter, which uses geiger tubes as the detector. It is an extremely sensitive instrument, having a range from 0.001 mrads/hr to 25 mrads/hr.



FIG. 5. The meter of the field ratemeter shown in Fig. 4.

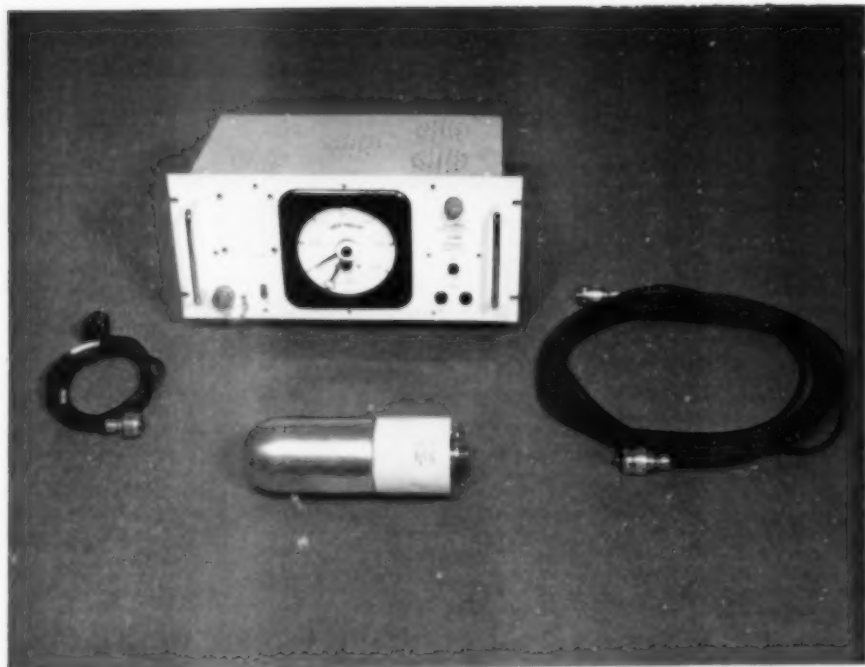


FIG. 6. A radiation monitor, which has a range of 10 mr/hr to 10,000 r/hr. The ion chamber shown is γ -sensitive only.

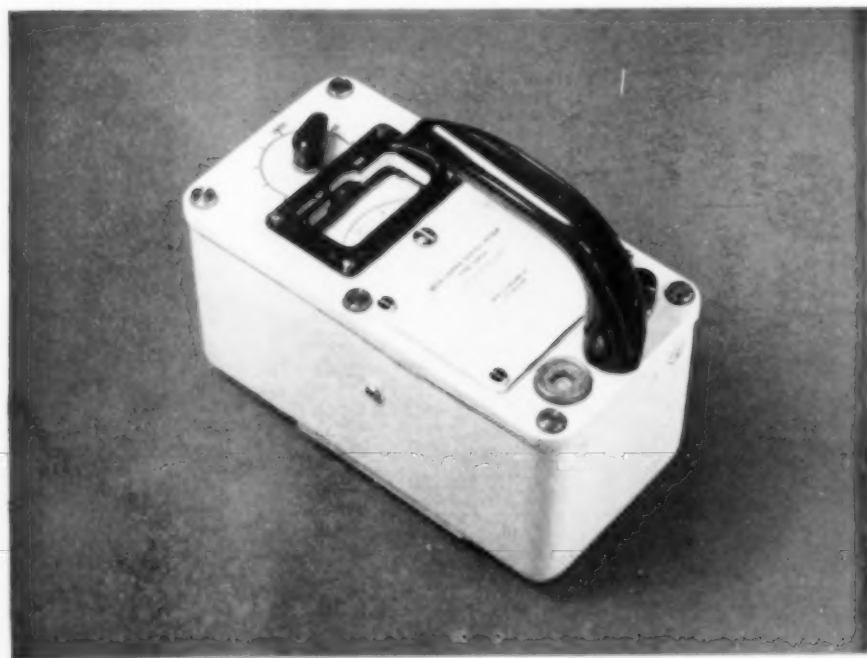


FIG. 7. A hand held β - γ survey meter. Using an ion chamber, it will measure dose rates up to 1.5 rads/hr. Similar models will read up to 15 rads/hr and 150 rads/hr. The edge of the hinged β -shield may be seen on the lower surface of the monitor.

γ -Energy (MeV)	Response (c/s per mrad per hr γ)
2.76	90
1.25	85
0.66	65
0.28	40
0.081	45
0.031	20

In practice, a reading of 100 c/s per mrad per hr can be assumed for energies above 1 MeV and 50 c/s per mrad per hr for energies between 50 keV and 1 MeV.

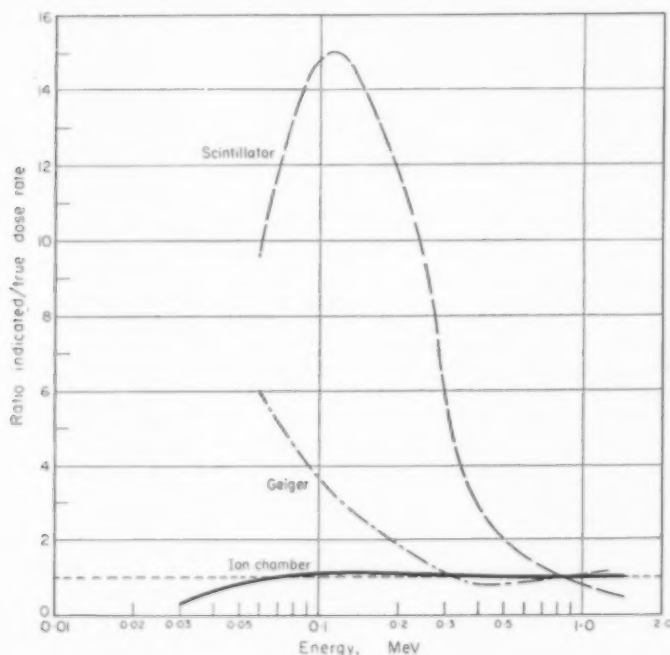


FIG. 9. Graph of γ -energy response of different types of detector.

Two instruments are available to detect changes in γ -background. In one (see Fig. 10) the ion chamber current is measured, tripping audible and visual alarms, when preset levels are exceeded. In the other the frequency with which an integrating ion chamber receives a fixed dose is monitored. Above a preset frequency, audible and visual alarms are triggered. The latter type was designed to give warning of transient high levels of radiation in a criticality incident.

6. CONCLUSION

For the successful control of the external β - γ -hazard each series of operations must be planned in advance, suitable equipment and monitoring instruments

provided and emergency instructions formulated. The operator must choose an appropriate instrument for the task and be familiar with its operation and limitations if he is to use it correctly and interpret the results intelligently. It should be remembered that all results are measures of exposure of an instrument and may not always correspond to the exposure of the man. Whether success has been achieved will be borne out by the results of the film badges worn by the operators.

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DISCUSSION

Lecture by: BARNES & GARDNER

DR. MCCALLUM, (Department of Industrial Health, King's College, Newcastle-on-Tyne):

It may be necessary in certain types of work, such as shipbuilding to carry a source of ionizing radiation close to the thigh for short periods. In shipbuilding the nature of the work may make it difficult for a man to keep the source away from the body. Can the speaker give any guidance on the use of film badges or dosimeters in this situation? Should a film badge be worn on the thigh or elsewhere as well as on the trunk? Is there any standard practice in use to cover this? There is presumably a potential risk of gonadal irradiation.

MR. VENNART (R.P.S.): It depends on the age of the man involved.

MR. SHERWOOD (A.E.R.E.) stated that in some circumstances at Harwell where the dose to gonads might be higher than that indicated by a film worn on the chest, film badges had been carried in trouser pockets. These had not in fact shown a significantly higher dose.

MR. COUCHMAN (Kent Alloys Ltd.) pointed out that distance can be made use of when carrying isotopes if two men are employed to carry the source slung on a rod between them.

MR. DUNSTER (A.E.R.E.) commented that it was necessary to determine whether the men in fact received the greater part of their dose during carrying or when the source was in use; he stressed the value of simple calculation and an operational analysis. He suggested that protection might be achieved by extending the carrying handle so that the dose is transferred to the feet and ankles which are allowed higher permitted doses than the gonads and blood forming organs.

DR. MARLEY (A.E.R.E.) remarked that it was the integrated dose which was the index of hazard. There was no hazard *per se* in high dose-rates if the times of exposure were short. In this connexion it was noteworthy that the I.C.R.P. in specifying maximum permissible levels no longer quoted figures for doses accumulated over periods less than 13 weeks and, indeed, the figures for concentration of radionuclides in air were average values for 13 week periods.

The PRESIDENT asked whether the wide differences in the sensitivity of the scintillation counter, geiger counter and ion chamber could be used to determine the radiation energy in the same way that different materials masking the film had been used for this purpose.

MR. GARDNER (A.E.R.E.) replied that the marked difference in energy dependence of the present geiger and scintillation field ratemeters (T. 1368 and 1413) has been used on a few occasions at A.E.R.E. to obtain a rough estimate of the energy of γ -radiation. Unfortunately, the accuracy is low, especially in the presence of radiation having a wide energy spectrum, and the results may be ambiguous.

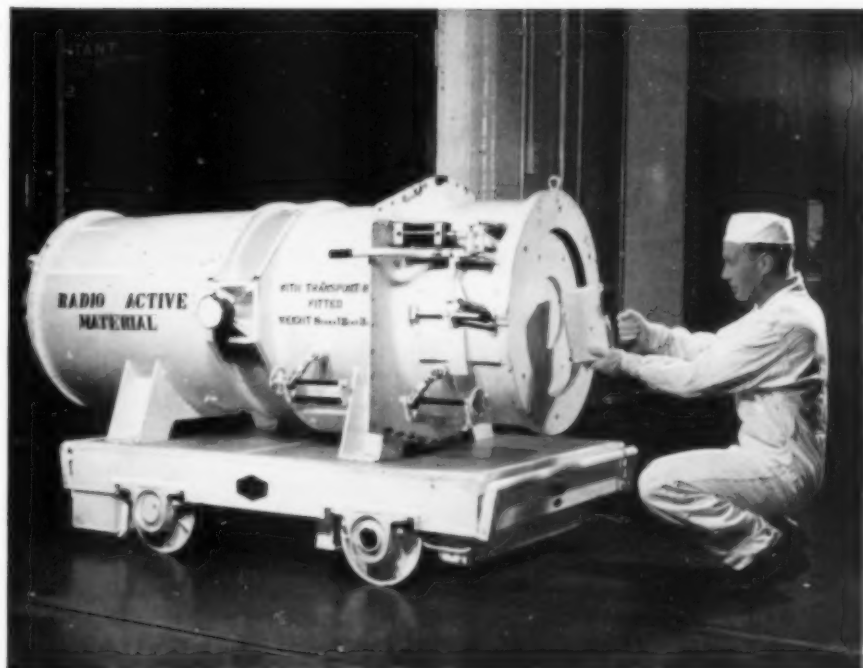


FIG. 8. A β - γ -survey meter (as shown in Fig. 7) being used to assess the radiation field around a transport flask loaded with a radioactive source.

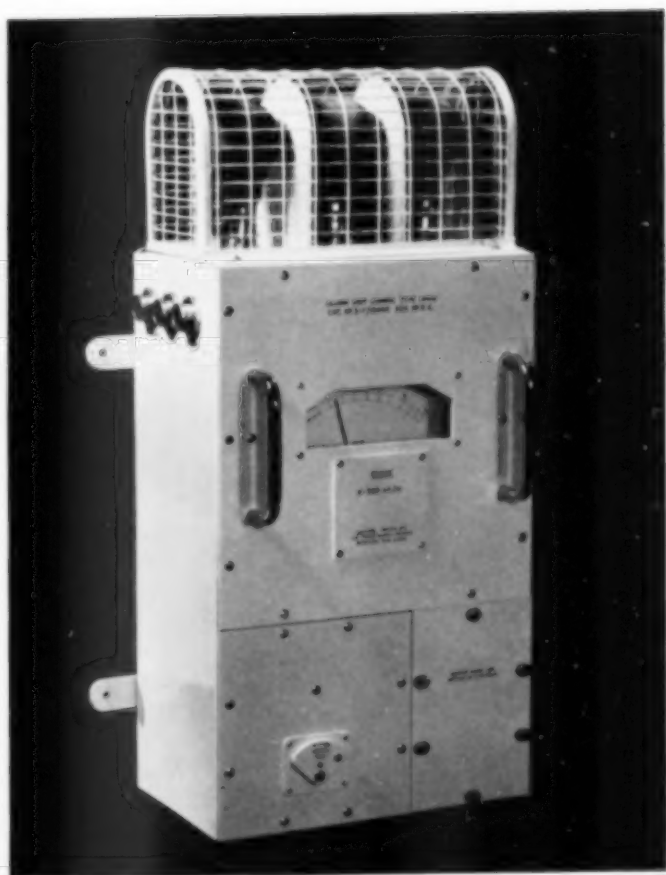


FIG. 10. A γ -background radiation monitor. It will trip two sets of audible and visual alarms, one at 30 mrads/hr and the other at 300 mrads/hr.

A comparison of the results from the two instruments may be of value where they are used to determine lower dose-rates than can be measured with an ionization chamber survey meter, which has a reasonably flat energy response. In these circumstances some reliance can be placed on an observation if both instruments indicate the same dose rate; if the two instrument readings are widely divergent, no great reliance can be placed on either.

Portable γ -spectrometers, powered by 12 V battery or mains supplies, are now becoming available, filling a long standing gap in operational survey equipment.

The PRESIDENT also asked whether anybody had an information about the proportion of observations, using the film badge and the quartz fibre pocket dosimeter, which had to be rejected because of technical failure.

MR. GARDNER replied that at A.E.R.E., in buildings where work with large β - γ -sources is undertaken, all staff wear quartz fibre pocket dosimeters in addition to film badges to allow close control of exposure. In one building with which the speaker is particularly familiar, where sources of up to 100,000c are manipulated, the 30-40 dosimeters in use are read daily (or more frequently if operations require) and are recharged weekly; approximately 1600 such weekly cycles being completed each year.

Minor inherent defects in the instruments are their slightly variable response with gamma energy (see Fig. 1) and their charge leak rate, which increases with age and rough usage. A more

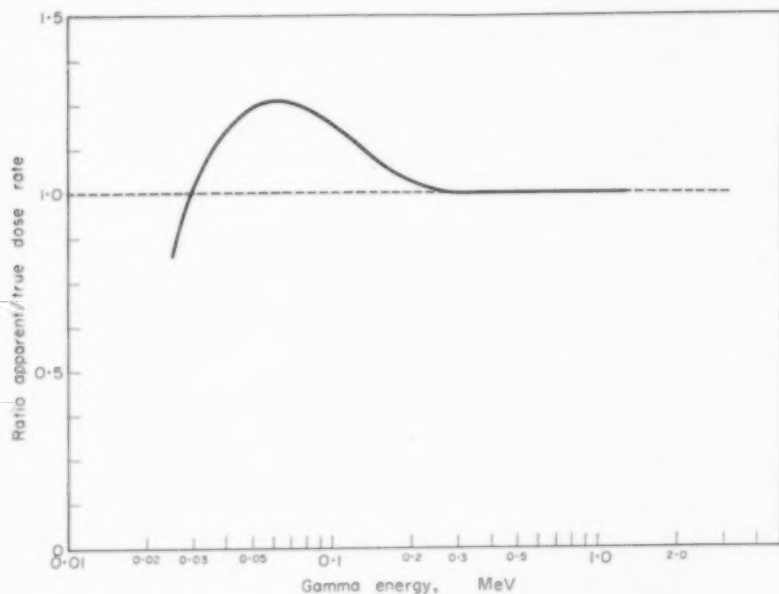


FIG. 1. Graph of γ -energy response of a typical quartz fibre pocket dosimeter.

serious defect is the delicate construction of the instruments. They are worn clipped on the outside of protective clothing and hence are sometimes dropped or knocked. This usually results in the quartz fibre being deflected, or even becoming broken. Often, the fibre is deflected towards the upper end of the scale, causing the wearer's absorbed dose to be over-estimated. Fortunately, it is much less common for the fibre to be deflected towards the lower end of the scale, reducing the indicated absorbed dose below that actually received by the wearer. During a typical year about 2 per cent of the readings are invalidated in this manner and in about 0.3 per cent of the weekly cycles the dosimeters are withdrawn as unserviceable due to a broken fibre or excessive leakage.

Due to the fragility of this instrument, when staff have to enter known high radiation fields (for instance, decontaminating a highly active cell) they wear an audible warning dosimeter, or a second quartz fibre dosimeter, in addition to their normal personal one and films. If either dosimeter indicates an abnormally high reading, then the operator's films are immediately withdrawn,

processed and his absorbed dose determined. With this system, films are sometimes processed unnecessarily, but all cases of high absorbed dose (e.g. 0.3 rad or greater for whole body exposure) are detected immediately and the operator can be given work in a much lower radiation field, thus ensuring that his total absorbed dose does not exceed the maximum permitted for the period under consideration.

The attached figures showing variation of energy response of quartz fibre pocket dosimeters are drawn from data supplied by F. B. Whiting, of Electronics Division A.E.R.E., subsequent to the meeting.

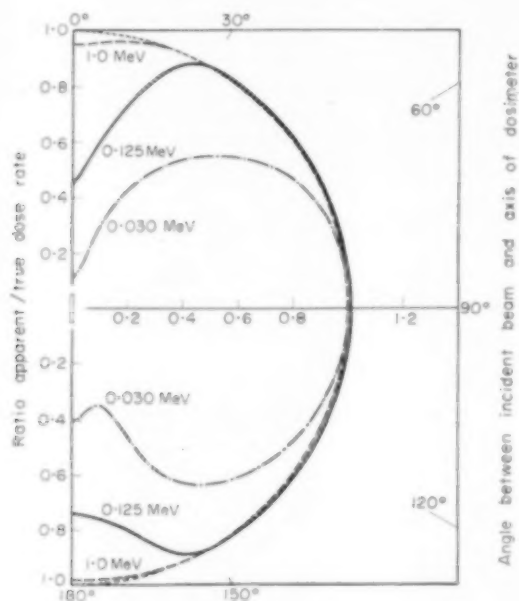


FIG. 2. Graph of response of a typical quartz fibre pocket dosimeter to γ -radiation at varying incidence angles. Angles are measured from the eyepiece of the dosimeter.

MR. M. J. HEARD (A.E.R.E.) said that technical failure of films is extremely uncommon and generally recognizable. A few films are fogged in manufacture though this is rare and generally recognizable because a run of several films may be involved. Films may also be fogged by light either as a result of faulty packing or subsequent damage to the envelope. The most frequent cause of light fog is the cutting of the packet by the numbering machine. This can be eliminated by careful pressure control. The light fog is normally confined to a part of the film so that the dose assessment is not completely lost. Films may also be fogged by excessive heat (above 60°C the effect is serious), by some chemical vapours such as mercury vapour, and by mechanical stress such as bending. In all cases the effect is generally recognizable as an artefact and it may still be possible to obtain a dose assessment from the film.

By far the greater proportion of observations which have to be rejected are genuine radiation exposures which upon enquiry are found to be "dose to film only". This is due to faulty use, not to faulty films.

W. E. POVER, (Dept. of Medical Biochemistry & Pharmacology, University of Birmingham).

In view of the speaker's remarks on the measurements of pencil beams using ion chambers; would he comment on how he would proceed to measure the dose rate escaping through breaks in the screening round an X-ray therapy machine? Would film measurements be in favour here?

Could they be used to define the beam and measure the dose received by the operator standing somewhere in the area of the control desk?

Should one in fact fill the volume possibly occupied by workers with film detectors?

MR. GARDNER replied that attempts to measure such narrow beams of X-rays should only be made with an ion chamber type instrument if the edges of the beam can be defined and the volume of the chamber exposed determined. The geiger type instrument should not be used due to its unknown response to X-rays. It should always be borne in mind that many geiger instruments do not maintain full scale deflection in a high dose rate. However, such an instrument could be used to detect the beam, and then small ion chambers (such as the BD. 11 type) or film badges could be used to estimate the dose rate at various selected points, such as in contact with the shielding defect and at the operator's working position, from which the operator's exposure could be deduced, taking into account duration of exposure. The results obtained could then be used to calculate the thickness of shielding required to attenuate the unwanted beams. Problems of dose assessment and subsequent shielding improvements can be greatly simplified by the use of large films to identify and locate radiation beams. Unless the X-ray energy and the response of the measuring device at that energy are known, by far the best technique is to use a selection of devices and consider all the results obtained.

THE MONITORING OF SURFACE CONTAMINATION AND ITS PLACE IN RADIOLOGICAL PROTECTION

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INTRODUCTION

MONITORING for surface contamination is a widespread practice in work with radioactive materials, but it is not usually a tool of the occupational hygienist and it is pertinent to ask why it is done at all. The contamination of surfaces by radioactive materials is objectionable from two broad points of view. In the first place, the contamination may result in a hazard to the health of the people working in the affected area, since they may inhale or ingest radioactive material from the surface and may be exposed to external radiation. The second objection is a technical one. Surface contamination may spread, causing contamination of sensitive measuring equipment and the cross-contamination of samples.

On both these counts, contamination is clearly undesirable and, as it is also fairly easy to measure, such measurements have tended to become part of the general technique of radiological control. Like most monitoring measurements they are easier to take than to interpret and it is easy to over-emphasize their importance. If it is remembered, however, that surface contamination is only an indirect hazard, via such mechanisms as inhalation and ingestion, it can form an excellent general indicator, in qualitative terms, of the degree of control which is being maintained in an area.

PERMISSIBLE LEVELS OF SURFACE CONTAMINATION

In spite of the qualitative nature of measurement of surface contamination, it is important to establish some criteria for deciding whether conditions in an area are satisfactory or not. It is not sufficient to say that any surface contamination is objectionable and must therefore be avoided, since this, in effect, merely relates the acceptable level of surface contamination to an arbitrary instrument sensitivity. It is obviously more logical to establish permissible levels for surface contamination and then to design instruments of the appropriate sensitivity. The derivation of maximum permissible levels of contamination of surfaces by radioactive materials has been discussed in some detail by DUNSTER (1955) and BARNES (1959). The values recommended for use in National Health Service hospitals are included in the hospitals' CODE OF PRACTICE (1957). The principles of the assessments underlying all these publications are the same and are derived from the recommendations of the International Commission on Radiological Protection. However, considerable freedom of choice exists in the selection of the values of the parameters needed to obtain permissible levels of surface contamination from the basic recommendations

of I.C.R.P., and care is needed in making use of the maximum permissible levels obtained. Simplifying assumptions have to be made at many points in the assessment and these result in permissible levels which are conservative, in some cases by a substantial factor. Thus, while it can be said with confidence that adherence to the recommended levels will result in radiation doses below those recommended by I.C.R.P., the converse is not necessarily true and, in many cases, higher levels of contamination may be accepted, either transiently or locally, without there being any risk of I.C.R.P. recommendations being infringed. On the other hand, levels of surface contamination in excess of those recommended usually imply either poorly designed equipment or inadequate attention to operating techniques.

As well as specifying the permissible surface concentration of radioactivity, it is also necessary to consider the area over which measurements may be averaged. In practice, the area chosen is usually that of the measuring instrument and will be of the order of 100 cm². Where large areas, such as floors, have to be monitored, there are considerable advantages in using an instrument with a larger measuring area, but the area cannot be extended indefinitely or the local radiation levels from highly localized patches of contamination may become unacceptably high.

Recommended values for maximum permissible levels for surface contamination and for averaging areas are shown in Table 1.

TABLE 1. RECOMMENDED MAXIMUM PERMISSIBLE VALUES OF SURFACE CONTAMINATION

Type of Area	m.p.c. ($\mu\text{C}/\text{cm}^2$)*		Averaging Area
	α -Activity	β -Activity	
Controlled Areas	10^{-4} $10^{-3}\dagger$	10^{-3}	300 cm ² generally 1000 cm ² for floors, walls and ceilings
Low-activity areas and inactive areas	10^{-5} $10^{-4}\dagger$	10^{-4}	
Skin	10^{-5}	10^{-4}	Whole of one hand 100 cm ² on other parts of the body

Notes:

* All the values refer to contamination which may be only loosely attached to the surfaces. Relaxations for firmly fixed contamination may be allowed at the discretion of the local health physicist who must bear in mind the type of contaminant and the expected future use of the contaminated surface.

† These values represent a somewhat arbitrary relaxation for α -emitters other than the most toxic ones. The values should be applied for contamination by the following materials:

Uranium isotopes
Natural thorium
Natural uranium
Thorium-232

Thorium-228 and thorium-230 when diluted to a specific activity of the same order as that of natural uranium and natural thorium

Short-lived nuclides such as daughters of the isotopes of radon.

OPERATING POLICY

Monitoring is a term borrowed from communications engineering and originally meant to check the quality or content of a transmission. In radioactive terms it means to check the quality of operating procedures and consequently some of the monitoring should be carried out by the operator himself. This monitoring by the operator is essential in laboratory work, but is less necessary, and less practicable, in industrial conditions. The operator has only a limited interest in contamination monitoring and usually has many other tasks which are, to him, more important. There is thus a need to provide a specialized monitoring service. This service usually forms part of a more general radiological safety service which provides monitoring of all sorts as well as detailed advice on the safety aspects of operations and design. The monitoring service can supplement operator measurements by conducting surveys during operations and can provide supporting services for monitoring floors, corridors, etc., which are likely to be ignored by the operator. In planning a comprehensive monitoring service, it is important to maintain a clear distinction between the monitoring of operations and the routine monitoring of areas. Operational monitoring is intended primarily to obtain information about a current situation and to provide the basis for immediate executive decisions. Routine monitoring, on the other hand, is intended as a check of the general situation and can be used to give an early indication of any long-term deterioration in conditions.

The frequency of both operational and routine monitoring must be judged by experience and no specific rules can be provided. The frequency will depend on the past operating record of the plant or laboratory and of the operators concerned, on the quantity of radioactive material available for dispersal, and on the extent of the danger to health or interference with operations which might follow the spread of contamination. In practice, work in any installation tends to start on the small scale and to build up, and this period of development gives an opportunity, both to the operators and to the radiological safety service, to establish good practice on a basis of common sense. It is important to review monitoring practices from time to time as such practices may become hallowed by constant usage. It is a good test of monitoring procedures to examine the use which is made of the results. If they are systematically converted into executive decisions and action then the monitoring is clearly necessary and entirely justified. If, on the other hand, results show consistently satisfactory conditions and no action is required, then the sole justification is the continued reassurance which they can give. In this case it may well be possible to reduce the amount of monitoring and to concentrate it at points where the first signs of trouble are likely to appear. Finally, if the results are being recorded but not used, the whole safety organization should be overhauled.

Contamination monitoring will rarely be the only type of monitoring carried out and measurements of radiation dose rate, personal radiation doses and radioactivity in air may also be considered necessary. Except in the case of some high toxicity α -emitters or of operations involving gases or vapours, experience has shown that the absence of excessive surface contamination is a reliable indication that the general housekeeping in the area is sufficiently good to make routine air monitoring unnecessary. This conclusion must obviously be used with some care since there is not necessarily a direct connexion between the processes which cause

contamination of air and those which cause contamination of surfaces. Nevertheless, it is a useful working rule.

CONCLUSIONS

Surface contamination monitoring can provide a general indication of the degree of control which is being maintained over operations with radioactive material. If contamination levels are below those recommended in Table 1 it is extremely unlikely that the contamination will be any danger to health. If the levels are above those recommended, the danger to health may still be negligible but attention should be paid to the standard of housekeeping, since the general control of contamination can probably be improved substantially without great difficulty.

Surface contamination monitoring has not become a tool of occupational hygiene in general, partly because of the difficulty of monitoring for non-radioactive materials on surfaces. However, it is a good general principle to avoid the indiscriminate distribution of toxic materials through the working environment and, if the techniques of measurement were easier, it is likely that the occupational hygienist would find the monitoring of surface contamination to be a technique as useful to him as it is to his radiological colleague.

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AIR SAMPLING—SOME PROBLEMS

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(Received 3 July, 1961)

PREVIOUS speakers have given the background to the reasons for carrying out environment surveys of all sorts in and around radioactive workshops. Mr. Dunster has gone so far as to indicate that a case could be made out for saying that there is little or no cause for a routine programme of air sampling. I think that this statement is too sweeping and that we could make out a good case for carrying out a routine programme of air sampling as an indication that the methods of containment and the standard of housekeeping in the radioactive workshops were being maintained. Our first concern, after all, should be to ensure by good design that the contaminant is contained at source; this we try to do. However, with the best will in the world, accidents and leakages occur and with the passage of time the standard of housekeeping and cleanliness deteriorates. I submit that a regular routine programme of air sampling gives a very good indication that conditions in the workshops and laboratories are remaining reasonable.

I wish to talk this afternoon about some of the problems which arise in air sampling, and not about air sampling as a whole. The subject is a large and intriguing one and there is much work yet to be done, so I will confine myself to a few of the problems which present themselves forcibly to the occupational hygienist faced with a workshop containing radioactive materials likely to produce dust.

OBTAINING A REPRESENTATIVE SAMPLE

A man standing in a contaminated atmosphere will be breathing air contaminated with dust containing a wide range of particle sizes; of these his lungs will probably only receive particles less than 10μ in size of a contaminant of unit density. Normally in a workshop he will be standing up working at his bench or perhaps sitting down at a table, or working at a fume cupboard or a glove box. Air currents within the room, the effect of gravity on particles, the flow of air into ventilation extracts and into fume cupboards, all affect the distribution of particles within the room and if we are to obtain a sample that is representative of what a man is breathing then the sample must be taken at about the position of his head when he is working. A man usually breathes through his nose or mouth and his normal attitude is with the head slightly forward. He does not normally throw his head back and stare at the ceiling whilst working so that the orientation of the sampling head must be considered. Obviously if a sampling device has its opening pointing upwards it will be collecting heavy material ($> \sim 20\mu$) which is falling

out as well as the suspension of airborne dust which forms the breathable environment and the sample will consequently over-estimate the hazard. It is difficult, for obvious reasons, to put air sampling equipment at the exact point at which a man is breathing. One therefore tends to put installed air samplers at about 6 ft 6 in. height from the ground, with a sampling orifice pointing horizontally or downwards, with a reasonable assurance that the air sampled will not be too far removed from that breathed by the man. Portable equipment can have its sampling head held, or fixed temporarily, reasonably close to the position of a man's head whilst he is working. It is of course important that such arrangements should not interfere with the safe and efficient manipulations carried out by the workman.

Another approach to this problem has been made possible by the recent development of a small personal air sampler developed under the direction of Sherwood at Harwell and described recently in the journals of this society. His sampler has a small head which can be worn in the lapel and is operated from a battery and pump carried in the pocket or on a belt. Some early results obtained with this equipment indicate that concentrations around the upper part of a man's body are as much as six times higher than those measured by installed air samplers about 10 ft away. With these figures in mind it is apparent that the use of personnel sampling equipment for investigating the working environment is an important technique in the occupational hygienist's armoury.

If our concern is the sampling of gases being discharged from stacks to the atmosphere again we must ensure that we have a representative sample and here we run immediately into the problem of ensuring that we obtain our sample under reasonable isokinetic conditions at points in the stack or ducting where we have undisturbed air flows. This usually means designing a sampling head, to fit in the stack or duct, which is small compared with its diameter and does not significantly disturb the air flow; air is sucked at about the same linear speed as the ambient gas. For practical purposes, providing that the head is sufficiently far along the duct from the last bend or opening or other obstruction, a reasonable sample can be obtained. A good working rule is to ensure that the head is a distance along the stack or duct from the last opening or obstruction or bend equal to 3 times the diameter. There are of course occasions when gas flows vary considerably and then one has a problem and can only assess the sampling rate in relation to individual circumstances; in general it is better to sacrifice isokineticism to the simplicity of a standard sampling rate and to rely upon the ventilation engineers to be able to produce reliable figures for the gas flows in the stack system.

There is a final problem concerning the representativeness of the sample. This occurs particularly in carrying out portable samples and in sampling in ducts. The actual location of the sample, i.e. the filter paper or vessel in which the sample is trapped, should in general be as close to the point of sampling as is possible. If a sample has to travel along a tortuous path from the point of sample to the actual sampling head, losses will occur due to impaction, possibly to diffusion and leakage, and our sample can no longer be representative. Where it is necessary, as for example in sampling ducts, to sample at a point with the collecting medium remote, the distance between the two must be reduced to the minimum and the pipe work connecting them must be smooth; bends, if any, must be of maximum possible radius and be few in number.

COLLECTION MEDIUM

Our next problem is to ensure that we are collecting all the materials sampled. This is again a difficult problem. For particulate matter it is standard practice to use various types of filter paper or in some cases membranes for the collection of the airborne particulates. In general terms filter papers are not 100 per cent effective collectors and collection efficiency is dependent upon particle size and the speed at which the air stream is sampled. It has, however, been shown that certain glass fibre type filter papers, if used at a sufficiently high sampling speed (greater than 10 cm/s), have an efficiency of sampling collection of about 95-99 per cent. They have, moreover, the other advantage that almost all the material is collected on the upstream surface of the sampling filter which helps counting efficiency for radioactive materials. Membrane filters can also be used. These are more highly efficient but suffer in that they generally require a very heavy pump effort and sampling speed is low. They are, however, extremely valuable as sub-standards against which to measure the efficiency of other collection media.

In the case of radioactive gases the problem is somewhat different. Techniques which come to mind include the absorption or adsorption of gases on to various materials and passing the gas into an ionization chamber.

Activated charcoal can be used to absorb iodine vapours and the ionization chamber technique for tritium.

CHOICE OF EQUIPMENT

The next major problem concerns the choice of sampling pumps and equipment. Here our problems are mainly those of engineering, the reduction of weight, the reduction of heat losses of the pump, maintenance of a constant pumping speed despite increasing filter loading, measurement of the air flow and the reduction of pumping noise.

Installed equipment can be provided with remotely located motors pumping through many hundreds of feet of pipe work from sampling heads installed in the suitable positions in the laboratories. Opinions vary as to whether or not it is necessary to ensure that each sample head has an individual pumping motor or whether a central motor and a mains-type pipe line pumping system can be used for connecting the heads to this motor. In general all obvious combinations have been, and are being, used. Powerful individual motors have the advantage of maintaining reasonably constant pumping conditions across a sampling head and they are undisturbed by changes which may occur at other heads on the system. It is possible to provide balancing chambers in the pipe leads to individual heads and use a central pump which again ensures that changes with individual heads do not affect other heads on the system. This type of sampling system is becoming more and more used. A further system is the use of what is virtually a vacuum system for sucking air through the heads. One central motor pumps down a large vacuum main, off which run $\frac{3}{4}$ in. vacuum pipes to the various sampling heads. If the pump is sufficiently large, and the main vacuum line sufficiently large, fluctuations in an individual line, either opening it up completely or shutting it down completely, do not significantly affect the other heads; this system has been used extensively in

other countries. It has the merit of being comparatively cheap, inconspicuous and simple.

Portable samples in the working space can be taken with electrically driven pumps or air driven motors. Electrically driven pumps, if worked from the mains, have the great advantage of being able to run continuously for long periods. They are comparatively light but may suffer, unless carefully designed, from over heating and generally require fairly heavy maintenance. Battery driven electrical pumping systems are inordinately heavy and even then have a short pumping life and again may suffer from over heating. They also, because they are battery driven, have a tendency to fluctuations and changes in the sampling rate. They are also noisy. Modern developments at Harwell on samplers run off pressurized air systems have the advantage of being comparatively light and silent. If the systems are run off air bottles, however, they have a short life and require the complication of connecting new bottles or recharging the bottles and it would appear that the logical use of such systems would be off installed high-pressure air lines in laboratories.

Relatively low-pressure air lines installed in laboratories can also be used to run air ejector pumps which are silent and small and, when fully developed, may prove extremely valuable. This type is particularly useful for obtaining samples close to a man's working area where the noise and space taken by more conventional samplers is a definite disadvantage. Finally, it is possible to run air sampling off service vacuum lines again with the advantage that the equipment is small and comparatively noiseless.

Equipment for measuring the concentration of radioactive gases varies with the gas concerned but in a typical case it would consist of a pump for drawing the gas through some form of ionization chamber or absorption bed. Equipment to do this must generally turn out to be fairly heavy and will always require electrical supplies either from the mains or heavy batteries. Equipment containing ion chambers has been designed for sampling tritium and is satisfactory, excepting that it is bulky and heavy.

PROCESSING AND ASSAYING

The problems of processing and assaying air samples of particulate radioactive substances are those normal to low level radioactive work. I do not propose to say very much about them. Generally speaking particulate samples are obtained upon filter papers and in addition to the collection efficiency allowance must be made for material being distributed throughout the filter so that much of the radiation is absorbed in the paper itself; corrections must then be applied not merely for collection efficiency but also for absorption in the paper particularly when dealing with α - and β -emitters. Here, however, membrane filters are a distinct advantage as perhaps 90 per cent of all the material is deposited on the upstream side and overall efficiencies are, to all intents and purposes, 100 per cent.

It is obvious that great care must be taken to ensure that counting heads do not become contaminated. Our approach is to make up our own scintillators by spreading ZnS carefully over the sticky side of Scotch type Tape and to view this directly with the photomultiplier. In the U.S.A. they tend to make up pre-prepared scintillator discs which are in intimate contact with the sample and are thrown away with each sample.

Materials emitting low energy β -particles such as Pu-241, Carbon-14, and Tritium compounds, present special difficulties because of absorption and it may often be necessary to carry out chemical extractions and then use normal radio-chemical techniques for estimation. An alternative approach is to find a liquid scintillator which can be used to soak the filter paper, render it translucent and then to count the light pulses obtained from this translucent scintillating filter paper. This is a process on which development is progressing.

CONTINUOUS RECORDING AND ALARM MONITORS

I have not talked much about the problems of obtaining samples to keep a continuous check on the variations of air concentration. There are many difficulties associated with such equipment in addition to the obvious expense. In my view they have limited use to the occupational hygienist. As a general rule operation should be arranged so that the environment is normally well below the maximum permissible concentrations for the radioactive materials in use. Such continuous monitoring equipments have their uses in assessing the effectiveness of the measures designed into the plan to eliminate sources of air contamination.

It has been suggested that such equipment should be used to control the working conditions by ringing alarm bells whenever the maximum permissible concentration is approached or exceeded. This seems to be a confession of design failure and if a laboratory can be shown to work normally at negligible levels of air concentration then it is not unreasonable to think that a man may work for a day on odd accidental occasions in levels 20 times those of the maximum permissible knowing that routine air sampling will show that there has been some form of spillage or leakage which can be put right. This is of course dependent upon there being a daily routine air sampling schedule. To me there seems to be a need for an instrument which would ring an alarm bell at, say, 160 M.P.C.-hr concentration, corresponding to about 1 month's intake of radioactive material at continuous exposure at the maximum permissible exposure level. An exposure of this order of magnitude would not produce a serious hazard, would be well within the exposure limits suggested by the I.C.R.P., and in my view would provide a reasonable working figure. Care must, however, be taken in using this technique when applying it to soluble natural uranium where the toxic properties are more limiting than the radioactive ones.

NATURAL BACKGROUND

A major problem in assaying very highly toxic alpha emitters such as plutonium is the presence in the atmosphere of small quantities of naturally occurring radon and thoron. These are present with their decay products in quantities which, in terms of activity, are up to 100 times the activity of plutonium at the maximum permissible plutonium level although this is of course many orders of magnitude less than the hazardous level and the M.P.C. for radon and thoron. Unfortunately the radon and thoron concentrations in the atmosphere vary from hour to hour from place to place and with meteorological conditions including changes of wind direction. It also varies according to whether one is inside or outside the buildings

and to whether there is any ventilation inside a building. There are also other variations in this level arising from geological considerations. The presence of radon and thoron in the atmosphere makes the design of continuous monitoring equipment for plutonium and some other highly toxic materials a very tricky problem. Their presence masks plutonium air contamination, and the daughter products from radon and thoron, which are taken up on the sample, must be allowed to decay before a final concentration of plutonium in the atmosphere can be obtained. Four hours will serve to eliminate the radon daughters but a further period of about two days is required to reduce the thoron background to a negligible amount. In a plutonium works it is not always convenient to wait for two or three days for a sample and some more rapid method of checking samples may be required. Various systems using coincidence counting techniques, β -absorption measurements, changes in α/β ratio, and other techniques are being developed for this purpose. Another approach is to use α -spectrometric techniques to discriminate the α from the plutonium from that due to radon and thoron daughters. If there is sufficient time it is, however, possible to count the sample 4 hr after collection, and again 20 hr later, and to compute on the basis of these readings the amount of activity to be attributed to the residual plutonium. This is possible because we are now dealing only with the thoron daughters and the remaining plutonium. This technique is useful where a day's delay is not important. In my own laboratories if we have apparently high samples, when compared with background samples of the atmosphere from clean areas, we count the samples at $\frac{1}{2}$ hourly intervals and plot a decay curve to give us an early indication of the plutonium levels.

CONCLUSION

I have indicated some of the problems likely to face the occupational hygienist in carrying out air sampling. They are problems with which we have to live and are familiar problems to all of us who have been working in this field for some time. Even so, they make the task of obtaining meaningful air samples a difficult one and when all has been done we cannot, as Mr Dunster said, use our air sampling measurements as a good basis for saying that a man has or has not inhaled or ingested radioactive materials. The only sampler that will do that, and then with reservation, is the man himself. However, we can, and do, use our air sampling techniques extensively and I believe we shall use them more extensively for ensuring that our processes have been designed and are being operated for safety, that cleaning and maintenance are being carried out efficiently and that a high standard of good housekeeping is being maintained.

Acknowledgements—I would like to thank my colleagues, Mr. J. A. Hole and Mr. B. Surman, for their assistance in preparing this lecture.

DISCUSSION

DR. NAGELSMIDT (S.M.R.E.) asked for an explanation of the observed discrepancies between lapel and fixed dust sampling results which differed on the average by a factor of 6.

MR. SHERWOOD (A.E.R.E.) replied that observations had been made in a large radiochemical laboratory containing many glove boxes where the pattern of air movement was highly complex. Weekly sampling results showed no correlation between a sampler worn by a man working at a glove box and two samplers installed nearby. The correlation reported was over a period of more than a year which is a significant period in relation to permitted exposures. The results seems to suggest that if a man produced the air contamination himself it was detected on his sampler, but

that the active cloud did not always reach a fixed sampler; if the activity was produced by another person in the laboratory this might be detected on the installed equipment but not on the personal sampler.

Did coal mining experience show a closer correlation between breathing zone and fixed position samples?

DR. FAY (N.C.B.) said that dust concentration measurements by a sampler worn on the man's chest and by another a few feet away were much more consistent on the coal face underground. Indeed, in a series of experiments carried out in the Pneumoconiosis Field Research no significant differences were found. It had to be remembered that on the coal face a relatively large number of men were working in a uniform pattern of ventilation, with a high velocity air-stream, compared with the less regular pattern in a laboratory. He was not surprised at the variations found by Mr. Sherwood, which were similar to those he had himself observed some years ago in a "hot" chemical laboratory at Harwell.

DR. MARLEY (A.E.R.E.): Experience showed that air contamination was always associated with work being undertaken in an active area.

MR. SHERWOOD (A.E.R.E.): This is borne out by the fact that on occasions when building ventilation has failed, and staff has been evacuated, no significant air contamination is observed in working areas, even though the flow of air into fume cupboards or shielded cells has ceased.

MR. SAXBY (A.W.R.E.): It has been shown that air contamination in corridors can be associated with the movement of staff to and from active areas.

MR. DUNSTER (A.E.R.E.): This might be due to contamination on active clothing. The sorting of active laundry, such as laboratory coats and overshoes, prior to washing commonly gives rise to measurable air contamination.

NOTES AND NEWS

U.S. National Committee on Radiation Protection and Measurements

A NUMBER of actions and activities of the N.C.R.P. and its sub-committees seem to be worthy of note at this time.

Just recently two new organizations have been accepted as sponsors. These are the American Nuclear Society and the Genetics Society of America. The N.C.R.P. is very happy, indeed, to have these two organizations assist in its programs.

Another action taken recently involved the reactivation of Subcommittee 1. This subcommittee under the chairmanship of H. M. PARKER met on 18 October 1960 and began a program reflecting its concern with the development of the basic concepts and philosophy of radiation protection. The subcommittee decided to operate under a pattern that has been found to be successful with other subcommittees. It will have a small working group assisted by an advisory group of consultants as circumstances demand. The initial membership includes:

H. M. PARKER, *Chairman*

R. H. CHAMBERLAIN

J. F. CROW

H. CURTIS

H. F. FRIEDEL

H. J. MULLER

C. POWELL

H. H. ROSSI

Subcommittee 14 on "Permissible Exposure Doses under Emergency Conditions" under the chairmanship of G. V. LEROY has been very active of late. A report of the subcommittee directed particularly to the problems of civil defence officials is now nearing completion and is expected to be submitted to the N.C.R.P. Main Committee in the near future.

Subcommittee M-4 on "Relative Biological Effectiveness" now under the chairmanship of V. P. BOND has also a new program. They have outlined a method of approach and begun preliminary work on a report. Arrangements have been made for liaison between this subcommittee and the joint I.C.R.U.-I.C.R.P. group concerned with similar problems.

Two new handbooks have been released during recent months and a number of others are now nearing completion. Handbook 72 on "Measurement of Neutron Flux and Spectra for Physical and Biological Applications" was released on 15 July 1960. Handbook 73 on "Protection Against Radiations from Sealed Gamma Sources" was released on 27 July 1960. Subcommittee 10 on "Regulation of Radiation Exposure Dose" has now completed the revision of Appendix B, "Suggested Regulations" of Handbook 61, "Regulations of Radiation Exposure by Legislative Means." In accordance with the decision reached at the 23 May 1960 meeting of the N.C.R.P. this revised Appendix B has now been made available to the States and other interested bodies in mimeograph form. It will be published as a journal article in the near future. The main body of Handbook 61 is also being revised and should be available shortly. Handbook 75 on "Measurement of Absorbed Dose of Mixtures of Neutrons and γ -Rays" and Handbook 76 "X-rays Protection up to Three Million Volts" (Revision of Handbook 60) are now at the printers and should

be released soon. Two other handbooks are now undergoing editorial review and it is hoped that they, too, can soon be released. These are: "Stopping Powers for Use with Cavity Chambers" and "A Manual of Radioactivity Procedures".

Identification of Medical Problems by Personal Medallions

A FOUNDATION has been established in California for the past 7 years which supplies bracelets and neck medallions with the purpose of identifying medical and health problems in the event of an emergency. Initially these problems included serious allergies, diabetes, haemophilia, heart trouble and other similar afflictions but the Foundation has now extended its scope to workers with various toxic chemicals. If a workman develops symptoms away from his place of employment any attending doctor knows immediately what hazard the patient is exposed to and can then determine whether this is a critical factor in the illness under consideration.

The medallion or bracelet is engraved on the back with the essential data and a serial number. The latter enables the Foundation to maintain a Control Reference File, which contains all specific information about the individual—his medical problems, full name and address, his own doctor's name, address and telephone number, etc. The Control File is available for information on a 24 hr basis. The program of the Foundation is being extended to other countries and Advisory Boards are being set up in Canada and Australia.

Further information can be obtained from:
Medic—Alert Foundation International
Turlock,
California, U.S.A.

ERRATA

Vol. 3, No. 3, p. 190.

In Table 1 the P.R.U. Handpump figure ascribed to DAWES (1956) should be 0.25 instead of 0.55 which reduces the mean value from 0.27 to 0.23. The table refers to sections 5.4 and 5.5.

"*Inhaled Particles and Vapours*" (Pergamon Press, 1961) p. 326,

Replies by DR. HEPPLESTON to the discussion on his paper.

First reply should read: "When haematite exposure commenced many of the silicotic nodules were in an advanced state, although some were composed of reticulín".

Fifth reply should read "Some of the nodules had reached the stage of hyalinization of collagen".

Eighth reply, line 3—for "entered" read "approached".

line 4—after "peripheral" insert "(i.e. respiratory)".

Vol. 3, No. 3, pp. 129–153, 1961 (C. JONES: Predicting the dry and wet bulb temperature of coal mines airflow).

It is regretted that the following tables of data were omitted from the captions to Figure 7 and 10:

FIG. 7.

Curve	Airflow (Q)		Duct Radius (R)		Duct Thickness (L)		Strata surface Temperature (θ_s)	
	m ³ /min	ft ³ /min	cm	ft	cm	ft	°C	°F
1	142	5,000	30.5	1.0	0.15	0.005	32	90
2	284	10,000	30.5	1.0	0.15	0.005	32	90
3	284	10,000	38.1	1.25	0.15	0.005	32	90
4	284	10,000	30.5	1.0	3.05	0.1	32	90
5	142	5,000	30.5	1.0	0.15	0.005	27	80
6	284	10,000	30.5	1.0	3.05	0.1	27	80

FIG. 10.

GRAPH	Airflow (Q) (ft ³ /min)	Roadway Radius (a, ft)	Strata Thermal Conductivity (Btu/(k, ft ² hr°F/ft)	Heat Transfer Coefficient (Btu/ft ² hr°F)
1.	12,000	4	1.4	1.75
2.	12,000	4	0.7	1.75
3.	12,000	4	0.7	0.88
4.	38,500	4	1.4	3.5
5.	38,050	8	1.4	1.57

Conversion Factors 1 ft³/min = 0.0284 m³/min.
1 Btu/ft² hr°F/ft = 0.0041 cal/cm² sec°C/cm.
1 Btu/ft² hr°F = 0.00014 cal/cm² sec°C.

Vol. 4, No. 1, September 1961.

(H. J. MAGNUSON: Recent developments in occupational health in the United States). Page 1, fourth line up from bottom: \$1.5 billion, should read million.



DR. ETHEL BROWNING receives honorary life membership of the American Industrial Hygiene Association (see p. 305).

TRAINING IN OCCUPATIONAL HYGIENE

*Proceedings of the 12th Conference of the
British Occupational Hygiene Society
Birbeck College, London, 11 April 1961*

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EDITORIAL

THIS issue of the *Annals of Occupational Hygiene* includes the papers and discussions of the Twelfth Conference of the British Occupational Hygiene Society. The meeting took place at Birkbeck College, London, on 11 April, 1961 and was concerned with Training in Occupational Hygiene; the morning session was devoted to the methods by which various branches of industry are at present meeting the call for persons skilled in this work and the afternoon session explored current and future facilities for training professional people who wish to take it up.

The need to expand the occupational health services available in the United Kingdom is being actively considered. Fundamental to such enquiries is the provision of facilities for the assessment and control of environmental conditions and their adequate staffing. The purpose of the conference was to examine the special knowledge required by people concerned with the health of workers, to consider from what quarters such people might come and how best to impart to them the skill and experience which they would have to use.

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MORNING SESSION

OPENING STATEMENT BY THE CHAIRMAN, DR. J. C. GILSON

Director, M.R.C. Pneumoconiosis Research Unit, Penarth, Glamorgan

THOSE of us who attended the Seventh Conference of this Society four years ago on "Instruments for Use in Occupational Hygiene" must have been impressed by the striking contrast between the amount of effort and money available for development of instruments for environmental measurement in the field of radiation concerning, perhaps, some 100,000 workers as compared with the money available for instruments used in the measurement of dusts, fumes, and toxic vapours for general occupational hygiene work in our quarter-of-a-million factories with their 15,000,000 working places. The limit seemed to be £5, or perhaps £50, for an instrument for general occupational hygiene purposes, whereas £500 or £5,000 seemed not unusual in the field of monitoring radiation.

We see the same disparity in the number of trained personnel. Those with a formal training in radiological health must now be well into the three figures, whereas those with a postgraduate training in occupational health in its wider sense which, of course, includes radiological health, can almost be numbered on the fingers of one hand in this country.

Following the Windscale accident the Veale Committee was set up and reported last year that during the next ten years training in radiological health will be needed for 200 Honours graduates, 300 other staff with a high proportion of graduates, and 600 technical staff, and it is envisaged that these people will all be engaged full time in the field of radiological health. This is presumably in addition to those who are already trained now. There are at least five universities providing postgraduate courses of a year or more leading to a higher degree in radiological health, and fifteen technical colleges and other centres providing shorter courses. In contrast, there is at present not a single university postgraduate course in the wider field of occupational hygiene. We shall hear this afternoon more details of any shorter courses there may be.

To me, this suggests a grievous lack of balance in our national effort to improve and control the environmental conditions of our factories and mines. I am not, of course, suggesting that we should take less care over the problem of radiation but if we can afford this great effort on radiation we can and should spare much more effort to ensure better environmental conditions for the main group of workers in this country who do not come in contact with radiation.

We may be told that things were not as bad as they were. This is, of course, in many ways true, but I think we should remember that it is now very nearly a hundred years since the first Act of Parliament making it compulsory to provide a mechanical means for the removal of noxious dusts (1867) and yet you see (Table 1) that in 1959 over 2,000 death certificates for pneumoconiosis were received by the Registrar-General, and that deaths from this cause far exceed those by accident in our factories and mines. You also see that although in some notifiable industrial diseases, for

example, lead poisoning, there has been a commendable improvement since 1930. There are others in which recent trends certainly give no cause for complacency.

TABLE I. DEATHS 1959: ENGLAND, WALES AND SCOTLAND*

<i>Pneumoconiosis</i>				
Mining and quarries	..	..	..	1593
Factories, foundries and misc.	..	..	..	457
<i>Fatal Accidents</i>				
Mining and quarries	..	..	..	382
Factories	..	..	..	598

NOTIFIABLE INDUSTRIAL DISEASES

	1930	1950	1959
Lead poisoning	265	57	64
Epithelioma ulceration	194	195	226
Chrome ulceration ..	95	143	192
Remainder	71	93	50
Gassing accidents ..	133†	242	206

* Figures for Scotland include only males.

† This figure is taken from Annual Report of the Chief Inspector of Factories. H.M.S.O., 1930.

The subject of our Conference is "Training in Occupational Hygiene" and there are many problems to answer:

- (i) Who should we train, engineers, physicists, chemists, or medicals, or should we train some of all?
- (ii) What should be included in the syllabus?
- (iii) What proportion of graduates to other staff should we train?
- (iv) What are the special needs of various industries and other employers, and is there a need for courses of different lengths?
- (v) Who is going to pay for the training?
- (vi) Will those who are trained find employment and a career in this work?
- (vii) Should there be a full inquiry into this problem along the lines of the Veale Committee but covering the general field of occupational hygiene?
- (viii) Last but not least, what shall we call these experts? "Occupational hygienists" is an inelegant name and has been misunderstood. We have "Health physicists"; why not "Health engineers", "Health chemists", "Health biophysicists", etc.?

To answer some of these questions—all of them, I hope—we have assembled here this morning an authoritative group of speakers representative of five major industries, and also of Management, the Unions, the Government, and, of course, Medicine. Our Conference opens very appropriately with a contribution by Mr. H. F. Spencer, Managing Director of Richard Thomas and Baldwins. Appropriate because Mr. Spencer, in addition to all his other cares, is responsible for the largest factory now being built in this country, on a site $3\frac{1}{2}$ by $1\frac{1}{2}$ miles, near Newport—the most modern integrated iron and steel plant in Europe. This will certainly raise many problems in occupational hygiene. Mr. Spencer, however, has such confidence in its future as a place of health and prosperity that he has agreed to it being named after him.

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HEALTHY WORKING CONDITIONS

HENRY F. SPENCER

Managing Director, Richard Thomas and Baldwins Limited

THE professions, and specialists of all kinds, like to use jargon. Your concern is with healthy conditions of work in industry. You call it "occupational hygiene" which appears to me, an uninitiated layman, to sound like jargon too, and, if I did not know differently, it might create resistance to it in my mind.

A self-employed boot repairer, a betting-bookmaker, a barman or barmaid, a lumberman felling timber, a ticket collector on a bus, a car park attendant, a duke's valet or butler, a steeplejack, a tic-tac man, are a few from a list of jobs which are "occupations". But I do not think your Conference will discuss their "hygiene". I wish you could have coined a more attractive name than "occupational hygiene" for your work, a name to appeal better to a business man's supposed practical mind. However, that is by the way.

As I understand your work and aims, they are directed to providing and/or improving the conditions, amenities, and services which would give the maximum degree of health and environmental comfort and contentment in industrial organizations, that is, in businesses employing an aggregation of labour—manual, clerical or any other kind, e.g. in factories, workshops of all kinds, mines, public services, stores, and so on.

No civilized industrialist today could object to that objective, whatever image he may have of "occupational hygiene". Now what, and how, can I, who have none of the appropriate scientific and technical knowledge which distinguishes the members here, contribute to this Conference of specialists? The answer must be, that even if I cannot make any scientific or technical contribution, I can, at least, bear witness from my own observation and experience, of the value of this work, the need for it, and for more of it. For even though I am an industrialist, I need not be reactionary. I have a reasonable amount of intelligence and am capable of critical observation. I have seen, in my Company, the fine work of our doctors, nurses, and welfare services, and, as they know, I have been more than ordinarily interested in particular forms of research by them into actual and suspected hazardous conditions provocative of physical or mental ill-health and danger. If I am therefore invited here to testify to the work and need of the services idealized by this Society, and to sustain a plea for their extension in industry, I do so willingly and enthusiastically; and I do indeed support you in wanting more trained personnel, and in the search for the best means to train a greater number. Yes, without doubt, the objects and objectives of the Society, and of this Conference, have my unequivocal support.

My mind and conscience are deeply grooved with the conviction that the world exists for human beings, that human beings matter above all else. No one would suggest that the world exists for money, gold, jewels, or for squalor, dirt, ugliness, disease, misery, nor for lions or elephants or donkeys, or even horses and cats and dogs, nor for natural scenery, which is only beautiful insofar as the human brain

and eye beholds and makes it so. For what else, then, should the reason of human beings make it exist, but for humans? And if industrialism is rational at all, then it is only rational if it is so enlightened that it furthers the security, health and welfare of humans.

The political and economic aims of the country, and of the civilized world, are to make life more bearable and useful. Industry is the heart of economics, the energy of economics, it is the mighty force which provides the food, raw materials, commodities of life; which furnishes the material standards of life, shelter, domestic amenities, transport, and so on.

Therefore, industry, and industrialism, should aim, at least, to prevent deterioration in life and, at best, to make human beings healthy (and insofar as it is essential to physical and mental health) wealthy, and wise—yes, healthy, wealthy and wise in the best sense of each word.

Which means, of course, that we should try to make life less expendable. That is what you want to do, and industry should help you to do it in any practicable manner it can command. For in the main, in industry, it is the healthy and the wise who do the best and most work, and certainly in leisure they secure the best and most satisfying contentment.

We must be frank with each other—the Society and the industrialist. You seek—and I support you—to do more in many cases, than legislation and statute demand. You are ahead of the law. You are conscience in action often before the law compels. I mentioned this because it costs money to build first-rate medical centres for routine or research work, it costs money to demolish or improve buildings which fall short of the ideal but still fulfil statutory obligations; it costs money often to improve conditions of employment which satisfy both the law and the Trade Unions; it often needs money for a firm or individual to take on obligations in industrial welfare which are not enforceable on all or voluntarily accepted as a standard by most; to scrap equipment acceptable for insurance, or which cannot be condemned by Government inspectors—it means money to do these things, and if there is none in the kitty, a conscientious employer is very worried at falling below a high standard of employment conditions. And there are conscientious employers who may be in this predicament and unable to move as fast in your direction as they would wish. I have great sympathy with them. Nevertheless, I feel the time must come, and not too distantly, when it will reflect critically and adversely on any person, firm or industry, where the utmost effort has not been made to provide a working environment which, at the very least, will not endanger physical health or create mental friction. I could prophesy that at no distant date, the non-availability of capital to provide a healthy working environment will reflect so seriously on any industrial establishment that it will recruit only the poorest workers and consequently produce uncompetitive inferior goods.

Gentlemen, medical and technical experts follow me, and whilst I can talk with sincerity, and some passion, of the need for what you call "trained occupational hygienists", I am not qualified to talk about how they should be trained.

Fifty-six years ago I was sent to work in a Midlands iron foundry, as a sand boy, for I belonged to the now almost forgotten class whose compulsory elementary education ended at the nearest holiday break to his thirteenth birthday—I think it was the nearest holiday. But whatever it was, the economic needs of the times and the conditions of my social class half a century or more ago, forced boys like me to

go to work at 13. That was the time when the rate of pay was 3s. a day of 12 hours for unskilled workers, no health or unemployment insurance, and, if I remember correctly, no obligation to give a week's or any notice to a worker. I well remember that if there were no work for my father, which frequently happened, he was sent home without pay. They were hard times.

I have known well, therefore, the working conditions in industry for a very long time—for a working life of 56 years *is* a long time, and I can speak from practical experience of the old wretched conditions. Since that time there have been great changes, from a reluctant evolution born of social dissatisfaction and industrial serfdom, to the present day of almost equipoised power between organized labour and professional industrial management.

Experience, intellect and emotion combine in me to support you wholeheartedly in the scientific study of working environment, in seeking the most complete analysis of all the components of working environment, physical and mental, in the separation and elimination of the harmful, and in the invention and development of the right conditions to minimize physical and mental frictions and hazards.

I only wish I could play a scientists' part in this work. All I can do, and all industrialists can do the same, is to give you such moral and financial support as is within our power to command. I think I may say that I have tried to do this in my own Company, though I was preceded in my job as Managing Director by other humanists and consequently I found the climate of opinion already formed. For we established our Medical Service, under Dr. Spickett, nearly twenty years ago, and we have been extending and improving it ever since. There was, naturally, some inertia in the early years, but we are moving more quickly nowadays. We are, of course, long past the phase of thinking of our Medical Service as first aid or compensation thrift. I think I can claim that we have now established a comprehensive Medical Service covering all our plants, and we are a fair-sized company employing over 27,000 people, and very soon it will be getting on for 34 or 35,000.

We have doctors and others of an enquiring mind, greatly concerned with the problems of working environments and with the manual actions and mental reactions of the man on the job, and with the composition of the material on which he works. They are working hard towards systematizing accurate scientific observation and measurement of work itself and the conditions enveloping it. The operation of our Medical Service has revealed the need—the urgent need—to go deeply and scientifically into various situations which have actually affected, or might affect, the health of our workpeople. Though I must emphasize that our Central Medical Laboratory has developed on a gradual basis, not as a general research unit, but essentially to carry out thoroughly *ad hoc* investigations within the Company on the basis of the need for results in a reasonably short time. This small special Investigatory Medical Unit is manned by a doctor, an occupational hygienist and a bio-chemical laboratory technician. We shall go on developing and improving this service because it is giving results, and our doctors present to-day are best able to talk of those results.

But I know we are carrying out successful and useful investigations into our own environmental conditions which are suspect, and other medical problems in our workpeople which lead to suspicion of any buildings, atmosphere and work contact. I believe there are no official bodies who will carry out the intensive local investigations such as are required; that background knowledge of the industry is essential,

and that strangers would be at a great disadvantage in not working within the framework of a well developed and well trusted local medical service.

From what I can see it seems necessary that any unit, which is established, should work closely with the medical officers, and it is essential that all members of it should be scientifically trained. I am told that training in the special techniques required is difficult, because there are as yet no training facilities available in this country, though, if I am correctly informed, it is the intention to start a training course in September of this year at the London School of Hygiene. If that is so, I wish it well.

It was certainly not easy to establish our unit. When we decided to appoint an occupational hygienist, we could not find a trained man, and we had to appoint a physicist, only to discover that to provide him with a formal course of training, we should have to send him to America. Through the goodwill of some other organizations, and the co-operation of our own doctors, we are overcoming our training problems, but our experience emphasizes the need for formal skilled instruction, and confirms the need for, and importance of, this Conference. There are special techniques and principles which are basic to this technology of Occupational Hygiene and I think our own Chief medical officer is of the opinion that they are so important that every industrial medical officer should be trained in them, although at present only a few in the country are so trained. Now it seems to me that the future development and extension of occupational hygiene which we all want to see take place must depend on individuals believing in its effectiveness, and it is reasonable to expect that this effectiveness would be more quickly demonstrated, and more widely supported as indispensable, if all or most industrial medical officers had declared their faith and enthusiasm in it by themselves acquiring and practising its techniques and principles.

If industrialists think that at the beginning it is essential to set up large expensive central investigatory units it could retard the rapid development of this service, for only big firms could afford these, but an enthusiastic medical officer, skilled in its techniques, backed only by a technician with basic laboratory facilities, could do much quickly to proselytize by proving its economic and social benefits.

It should be unnecessary in these modern days of education and social conscience to say any more than I have said about the economics of the service, but if there are any industrialists left who say, "We will spend no more money on a service to improve the health conditions in our factories, already up to statutory standards, unless it can be shown to pay for itself or yield a profit", let me just add these facts. Any improvement in the atmospheric conditions in buildings, such as the elimination, channelling or collecting of dust, gases, fumes, humidity, and so on, adds to the life, and reduces the maintenance of, the buildings. It also eliminates or reduces damage to stored goods and any installed machinery.

Environmental hazards increase absenteeism, lower efficiency, and reduce production and productivity. They can result in claims for special rates for unpleasant jobs, for longer rest times and bathing times, and predispose to accidents and even fatalities.

Competent and conscientious workmen are attracted to the best conditions of employment and to the most enlightened employer. Whatever the cost of maintaining the health and well-being of the worker, if the service is efficiently carried out, whatever the cost, and wherever it figures in the accounts, it will not be an expense, but a profitable investment, even if it cannot be evaluated by an accountant.

Mr. Chairman, I have already said, I am not qualified to advise on the kind of training required for an occupational hygienist. Those who follow will be able to do that. I hope, Mr. Chairman, that this Conference will lead to still greater co-operation between industry and the medical profession, and to a significant expansion of the occupational health services of this country.

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TRAINING IN OCCUPATIONAL HYGIENE

JOHN ROGAN

Chief Medical Officer, National Coal Board

IN this paper I propose to describe existing arrangements for the maintenance of occupational hygiene in the coal mining industry, to evaluate these critically and to consider how they may be improved.

It may be useful at the outset if I give you a thumb-nail sketch of the industry. It produces about 200 million tons of coal a year from some 700 collieries. It owns one third of the coking plants in the country, also manufactured fuel and by-product plants and brickworks. It employs rather more than 600,000 people.

The industry is very large. As you may imagine, largeness of an industrial enterprise carries with it difficult problems of management. But it also has many advantages. In the case of the coal industry it has made possible highly organized and integrated medical, scientific and engineering services with considerable resources for research and development.

The environmental problems concerning the industry are formidable but probably known to most of you and therefore I shall only mention them briefly. The most difficult is the maintenance of a reasonably pure atmosphere underground free from excessive dust, and from toxic and explosive gases. An illustration of the ventilating effort required in the mines is the weight of air pumped through the colliery workings each year, 1,000 million tons. There is a difficult lighting problem. In some mines natural conditions are unduly hot and humid. The mining process is of course intrinsically more dangerous than most other industrial processes. Finally, many small environmental problems common to industry at large are also encountered. Occupational hygiene is thus of cardinal importance in this industry.

Now I shall consider existing arrangements for occupational hygiene. If these are to be understood the structure of the industry must be indicated. The Headquarters of the National Coal Board, which includes all functional departments, is situated in London. The coalfields are divided into nine Divisions, each with its Divisional Board and departments similar to those at Headquarters. The next level is the Area and there are 45 of these, each under an Area General Manager with full departmental staff. Then come the collieries. The engineers are employed in Production Department, the scientists in Scientific Department and the doctors in the Medical Service. All three Departments function at Headquarters, Division and Area. Research and Development is controlled by the Departments at Headquarters.

The industry employs about 75 doctors and 480 scientists, the majority of whom are chemists and physicists, though some are metallurgists, mathematicians, etc. Some 350 nurses and 1150 technologists are also employed in the Medical Service and Scientific Department.

I now come to the question of training in occupational hygiene. The Board's doctors are all trained in this subject; most have had special post-graduate training, others have learnt the subject on the job. The scientists and engineers have had no

formal general training in occupational hygiene at all, though most have had some specific training for a particular aspect, for example, in dust suppression, dust measurement, air and water analysis. Both scientists and engineers have to acquire a general knowledge of occupational hygiene from the medical staff, from various conferences which they may attend and from a study of the literature.

What are the merits and demerits of the present system? To take the merits first, generally speaking the industry receives a good occupational hygiene service. It is not perhaps as good as it might be when some unusual problem arises. However, in such an event the research establishments are extremely helpful, the Mining Research Establishment at Isleworth, which is responsible for research over the whole field of mining operations and the Central Engineering Establishment at Bretby which is responsible mainly for the development of mining machinery. The organization of the industry is such that liaison between the doctors, scientists and engineers is natural and easy. The fact that they have good career prospects enables us to recruit graduates of sufficient quality.

The most obstinate problem in occupational hygiene in the coal mines is dust. Dust suppression calls for expert knowledge of mining techniques in general and of highly specialized dust suppression techniques in particular. It is idle to suppose that this knowledge should be possessed by an occupational hygienist, however well trained. Moreover, were we to employ occupational hygienists, the nature of their training would, I think, materially restrict their career prospects and this in turn would adversely affect the quality of recruits.

The present system could undoubtedly be improved by courses in occupational hygiene for men already employed in the industry. The duration of such courses would be of critical importance. Nine months would be out of the question. Three months would be very difficult. One month is probably the longest course which would be practicable. It can be argued that the one month course is very short. So it is, but it should be remembered that the students would be graduates who already had considerable knowledge of environmental problems and would be familiar with an industrial background. Their capacity to assimilate knowledge about occupational hygiene would thus be well above average. So far as pre-employment courses in occupational hygiene are concerned, I am doubtful if students will take a nine months' course. A three months' course possibly run in the summer vacation would seem to me more practicable.

I must frankly admit that my judgements on occupational hygiene are highly coloured by my own experience in the coal industry. But I should be surprised if they were not valid over a large sector of industry in general, especially that sector embracing the larger concerns.

Finally I should say that the views which I have expressed are entirely my own and do not commit the National Coal Board.

HEALTH IN THE HEAVY CHEMICAL INDUSTRY

K. P. WHITEHEAD

Division Medical Officer, I.C.I. General Chemicals Division

UNLIKE Dr. Lloyd Potter, who was originally invited to address you here this morning, I am hardly qualified to discuss this subject in relation to Imperial Chemical Industries, Ltd., as a whole and I shall, therefore, confine most of my remarks to that part of the company which is familiar to me—the General Chemicals Division.

This division, of which about three-quarters is situated in the Widnes and Runcorn areas, on Merseyside, is made up of two distinct types of factory, the acid factory, manufacturing acids such as hydrochloric, sulphuric, formic, oxalic and chlorosulphonic and the chlorine factory, which produces chlorine from the electrolysis of brine.

Although much of the chlorine is liquefied and sold, large amounts are used for the chlorination of a host of organic compounds, to produce chlorobenzenes, chlorinated solvents, such as trichloroethylene and perchloroethylene, chlorinated phenols, chlorinated waxes, chlorofluoro compounds, vinyl chloride and many other materials. Metallic sodium is also manufactured from salt. Hydrocyanic acid is handled in large quantities to produce acrylonitrile and methyl methacrylate, an intermediate in the production of perspex. The Division also embraces Plant Protection Ltd., which manufactures products for the agricultural market. These include such materials as the organic mercurials and the organic phosphorus compounds. In addition, there is a large research organization with its laboratories and pilot plants.

I have thought it worthwhile to give you this very brief outline of the Division's activities to enable you to have some idea of the diversity of the chemicals handled and to emphasize that one of the main problems in the industry is the recognition and control of the toxic hazard.

The principal source of industrial illness among employees in this industry is likely to be from the inhalation of poisonous fumes, gases and dusts, or from the ingestion or absorption through the skin of chemicals used in the various processes. It is obviously, therefore, quite imperative that if the health of personnel is not to suffer, that full information should be available on the toxicity of various substances to which they are exposed, as it is only with this knowledge at hand that adequate precautions can be taken on the plant.

The Division Medical Officer is a key man in the organization. Apart from his duties of general supervision of the medical service, he it is who is consulted on precautions to be adopted on the plant when dangerous substances are used and his opinion is sought in the designing of new plant and lay-out of sites. His experience and training generally enable him to answer the questions put to him, but quite often there arises the problem of working with new substances whose toxicity has not been established, or with which he is not familiar.

The Industrial Hygiene Research Laboratories, founded by this Company,

exist for the purpose of supplying the toxicological information he requires to carry out his function. The laboratories were set up just after World War II, at Welwyn. They are independent of divisional control and are, for administration purposes, under the Head Office Medical Department. They have a separate administrative head and are divided into four sections:

- Pathological
- Physiological
- Chemical, including biochemical and analytical
- Information

The procedure normally adopted is that when a Division Medical Officer requires toxicological data on a substance, he sends a sample of it to these laboratories, together with information about its chemical and physical properties, the use proposed for it and the conditions under which it will be used. On receipt of the enquiry it first goes to the Information Section, where there is a substantial card index of abstracts of toxicological literature. Should there be insufficient information in the literature to answer the enquiry, it is passed to the experimental sections, where the animal experiments necessary to supply the data required are carried out.

The findings of the laboratory are sent to the Division Medical Officer in the form of a report. This report contains information from the literature, results of animal experiments carried out at the laboratory, an interpretation of these results in human terms, advice on the precautions to adopt and in case of vapour hazards, suggestions as to the toxic limits of concentrations to be permitted in the atmosphere. The Laboratory acts only in an advisory capacity and it is the duty of the Division Management, on the advice of the Division Medical Officer, to prescribe the conditions of use and the precautions to be taken with the substance. The Medical Officer is responsible for confirming the results of the tests carried out at the Laboratory, by clinical observation of the employees using it.

It can well be appreciated that the service given to us by the Industrial Hygiene Research Laboratories is of tremendous benefit to Management, in laying down a policy for satisfactory working conditions in their various plants. These conditions are maintained by careful supervision and co-operation between plant manager, safety officer, engineer, chemist and doctor. Where necessary periodical atmospheric tests are carried out. This close liaison between various sections and departments is normal practice and indeed is essential if good working conditions are to be maintained. We have, for instance, a large mercury vapour hazard and to control this hazard, it is necessary to have the services and advice of almost every profession in the factory. The engineer is concerned, particularly with the ventilation of the building, whilst the analytical chemist tests the urines of employees for mercury content and albumin. The latter is also responsible for routine testing of the atmosphere. Constant attention is paid to good housekeeping and this is the normal duty of the plant manager. The Medical Officer pays routine visits to the plant and also carries out periodical medical examinations on personnel working there. Major problems, concerning the working environment are discussed at meetings at which representatives of all interested parties are present. Day to day problems relating to heating and ventilation are dealt with by the Works Managers and their engineers. General lighting requirements and light measurement are the responsibility of Power Department and where advice is required on colour schemes, it can be obtained from experts in our Paints Division.

Noise measurement and control is a comparatively new field, but is dealt with basically as an engineering problem. Noise measuring apparatus is expensive and is not generally held in factories. The apparatus is, however, loaned from works to works and is then used by engineers in the various factories to carry out measurements in the appropriate places. Noise is not a common problem in this industry.

Ionizing radiations require a careful control and regulations have recently been laid down by Government decree. The responsibility for administration is again with the works manager, advised by the "competent person", who is in most cases a physicist or chemist. The control of effluent is again a matter for the chemist and engineer, working together. The day to day work in the control of plant environment is carried out by experienced employees. These employees are not as a rule university graduates, but hold one of the National Certificates in one of their respective subjects. In each case, he or she is responsible to a senior chemist or engineer.

In this short paper, I hope I have been able to suggest to you that there is little need for the employment of an industrial hygienist in a large well organized industry, in which it is possible to call upon experts in any given field to provide a first class opinion on the many problems with which we are concerned. I do, in fact, find it very difficult to believe that one man could become competent over so wide a field.

I would like to make it quite clear that I am not condemning the idea of an industrial hygienist, as I feel certain that in smaller industries, without the facilities which I have described, he has a very important role to play. I am aware that many small factories on Merseyside have the greatest difficulty in obtaining advice and help on the various environmental problems which confront them and I have little doubt that the employment of an industrial hygienist, perhaps on a group basis, would be of considerable benefit.

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THE WORK OF A HYGIENIST IN THE PETROLEUM INDUSTRY

E. H. CAPEL

Chief Medical Officer, Esso Petroleum Company Limited

(Read by P. G. SWANN, Assistant Chief Medical Officer)

I HAVE been requested to give, in this paper, my views on the need for occupational hygienists and the type of training which they should receive. I propose to do this in relation to my own company by outlining our problems and the ways in which we have handled them, concluding, from this experience, with my views on the training necessary for an industrial hygienist.

I must start, therefore, by saying something about my company, its set-up and its products. It employs, with its affiliates, about 14,000 people, of whom 3800 are at its main refinery at Fawley, Hants, 350 at its new refinery at Milford Haven, 2000 are sea-going and the remainder—some 8000—mainly engaged in marketing. As I have said, we have two refineries, the larger at Fawley being the largest in the British Commonwealth and the second largest in Europe. The sea-going fleet consists of 29 tankers with a total tonnage of 704,737. The marketing organization consists of 7 large units, called terminals, where storage, some processing and packaging of goods is carried out, and approximately 110 small storage units called bulk plants. In addition, we have air force storage depots and storage and refuelling depots at most major airports. Bunkering of ships is provided at the sea ports. The Esso Research Company operates chemical and engineering research laboratories at Abingdon. In addition, there are laboratories in many other places, as well as office groups of varying sizes.

The company's products include the straight petroleum distillates such as petroleum gases, petroleum, kerosene, white spirit, fuel oil and asphalt. They include lubricants which contain special additives, and also synthetic lubricants. Many special solvents are made. The Speciality Department handles such things as anti-freeze, insecticides and some pharmaceuticals. The whole range of products and substances manufactured or handled is much too big for me to give a complete list. Likewise, it is impossible in the time, to give any outline of the many different manufacturing processes in use.

There is a very wide range of occupational hazards and industrial hygiene problems. The greatest number of hazards undoubtedly exist at the refineries, but one must always remember that elsewhere—for example on the marketing side—where the hazards may be less, the operatives are generally less skilled, there is less direct technical control and a considerable amount of industrial hygiene supervision is required.

Of the many existing hazards, those of inhalation of chemical vapours and dusts is a large one. These include hydrocarbon vapours—petrol, kerosene, naphtha, benzene, etc., chlorinated hydrocarbons, methanol, creosote, hydrogen sulphide,

sulphur dioxide, phenol and many others. Tetraethyl lead is an important one, the main hazard existing at the refineries when blending and in marketing from tank cleaning. A very wide range of chemicals is handled in the various laboratories and mercury is one particular substance that has given us a little trouble. Many other hazards exist in some of the more out of the way sections of the company—carbon monoxide in the motor repair shops, cleaning or processing fluids in printing and duplicating, lead fumes in plumbing and so on. The control of these hazards, in general principles, is based on the substitution of a less toxic chemical where possible, e.g. toluene for benzene, trichlorethylene for carbon tetrachloride, improved general ventilation, local exhaust ventilation, the use of fume cupboards; respirators, the avoidance of spillages, traps and other well known methods as appropriate in the circumstances.

Dust hazards arise principally from sand blasting or from the various silicate and other catalysts used. Vanadium dust from flue cleaning is another hazard. The control depends upon enclosure of the dust, the use of exhaust ventilation or suitable respirators.

There are many skin contact hazards—from those that are acutely caustic—such as phenol, to primary skin irritants, skin sensitizers and substances that are carcinogenic. Very many, in fact most of the different liquids used in the industry come in one or other of these categories. Of particular importance are the heavy aromatic oils and creosotes which are carcinogenic. Protection is provided by mechanical handling to avoid skin contact, the use of protective clothing, barrier creams and shower baths at the end of the working session. In the case of carcinogenic products, regular periodic medical skin inspections are carried out.

We have no particular ingestion hazards except those arising from canteen meals and to be fair, this is quite a small problem. Wherever possible, regular medical examination of canteen employees and routine inspection of kitchens, etc. is carried out.

There are a number of radiation hazards in the industry. X-ray examination of all tank welds is made at refineries and some other places. Radioactive tracers are used to follow reactions, to check mixing and blending processes and in various research projects. The use of X-rays in Company medical departments is also supervised. Control is provided by monitoring and by personal film badges. Protection is provided by screening and other accepted methods.

Noise hazards arise during servicing jet aircraft at airports, in tanker engine rooms and from furnaces, pumps, compressors, etc. at refineries and terminals. Control is provided by improvement in design, where possible, to minimize noise at the source, and by enclosure or sound absorption. Personal protection is provided, occasionally by ear plugs but generally by ear muffs, by restriction of the hours of work on a noisy job or by providing sound-proofed control rooms. All persons regularly exposed to loud noise receive periodic audiometric examinations.

Problems of heating, lighting and ventilation exist throughout the company with a few situations where particular difficulty exists, for example, that of heat and ventilation in engine rooms of ships, and on ships generally when passing through the Persian Gulf and Red Sea.

Lavatories, washrooms, mess rooms, canteens, locker rooms, drying rooms and such like, present, in addition to problems of heating, ventilation and lighting, exercises in public health and sanitation.

Apart from dealing with all of these situations as they exist, we are concerned perhaps even more with things in the planning stage. This concerns both new construction and repairs and involves a study of all new plans and process specifications, an enormous field of work in a rapidly changing and expanding industry like oil.

Over and above all these problems related to the Company's own employees, we recognize a responsibility to our customers and to the general public. We aim at maintaining an accurate knowledge of the toxicity and other possible harmful effects of our products and by labelling, instructions and advice, to avoid ill effects on users. Our hygienist has on a number of occasions, visited other companies to carry out investigations and make recommendations on industrial hygiene matters. Our concern with the general public arises from the possibility of company products producing widespread public health hazards, for example, motor fuel could provide dangerous fumes, insecticides could constitute a health hazard, or it could happen that our operating plant or procedure constituted a nuisance by noise, smell or the emission of toxic substances.

On the subject of administration, industrial hygiene is a function of the Medical Department and is a purely advisory service. In the past, before we appointed an industrial hygienist, it was carried out to the best of their ability by company doctors, making use of company laboratories or outside services for analyses.

In 1958, an Industrial Hygienist was appointed to the staff of the Medical Department and he works directly under the Chief Medical Officer and closely with the other doctors. All his reports are countersigned by one of the doctors before going out. This ensures that they all speak with the same voice and it is informative and educational in both directions. His working time is divided between the various sections of the Company. His only assistance at present is a stenographer and there is more work than he can fully cover. His accommodation consists of an office and a small physical laboratory, and he also has use of the medical department pathological laboratory for routine chemical or microscopic work. For other chemical work he makes use of one or other of the many chemical laboratories in our company.

Our hygienist has not had a formal training in industrial hygiene because such is not obtainable in this country. He holds a science degree in chemistry, with biology, physics and mathematics as subsidiary subjects and his background of experience is that of chemistry and process engineering in the oil industry. Since appointment he has been on a company course of training in industrial hygiene arranged by Esso Research and Engineering Company in the U.S.A. and has taken the Radiological Protection Course at Harwell.

As to the ideal training and background for an industrial hygienist, I feel this will vary somewhat with the industry. He must be able to talk the language of the other technicians, scientists and experts in the industry and I think a training, and preferably a degree, related to the industry's activities highly desirable. A good general background of science, including biology, is necessary, and this should be supplemented by training in the special principles and techniques of industrial hygiene. Whether this should be taught together, ending in a degree in industrial hygiene, or whether there should simply be a training in industrial hygiene on top of an adequate general science degree, seems to me immaterial. The general background of science seems to me the most important factor. The special principles

and practices of industrial hygiene could then probably be taught in about six months.

The personality of the individual is important and, in addition, the technique of putting things over should be taught. It must always be remembered that the industrial hygienist is all the time making suggestions and implied criticism of processes or working conditions that have already been established or planned by a supposed expert and this is difficult and liable to generate friction. Another need is to be able to be realistic and practical and not always too idealistic.

With our present set-up, the main deficiency is that there is much more work to be done than can be covered by a single individual. He is therefore engaged in the more obvious problems and those that can be dealt with fairly speedily and easily. Experience has shown what a vast amount of valuable work can be done using direct reading field instruments.

A description of our industrial hygiene problems and the set-up for dealing with them would be incomplete without a reference to the Medical Research Division of Esso Research and Engineering Company.

Esso Research and Engineering Company is an affiliated company of our parent company, Standard Oil Company (N.J.) and is engaged entirely on research connected with all aspects of company products and processes, world wide, and with process design and planning. It is located in New Jersey, U.S.A. The Medical Research Division is concerned with research into the toxicology and other health aspects of the company's products, the things it handles, manufacturing processes, working conditions and so on. It has an industrial hygiene branch engaged in the industrial hygiene aspects of this work. Some of the research work of the Medical Research Division is carried out in their own laboratories, some field research done in the company plants and some research put out to universities and other appropriate bodies.

The Medical Research Division is of the greatest value to us in keeping us regularly and fully informed with all the toxicological data concerning company products, materials handled and a great deal of other basic information. The information service also covers all the industrial hygiene applications such as radiation, heat, cold ventilation, noise and so on and includes recommended principles and standards. It provides a card index abstraction service covering all our interests in toxicity and industrial hygiene. Information is obtained and advice given to us on any special problems we may raise and, if necessary, research on the subject will be instigated. The Medical Research Division will send a research team to this country to carry out industrial hygiene studies or research on request.

This service, of course, costs money and has to be paid for. The service is provided world wide for the affiliates of Standard Oil Company (N.J.) and the cost is charged back to these companies. In my view, it would be extremely difficult to operate a satisfactory industrial hygiene programme in an industry with complex chemical problems such as ours, without a research and advisory service like this.

To conclude with a final note about our own industrial hygiene service, this has now been operating something over two years. I am most satisfied with our results. Some very interesting problems have been unearthed and, what is most satisfying is that a very high proportion—in fact very nearly all of our recommendations have been adopted.

HEALTH SUPERVISION IN INDUSTRY

H. COLLISON

Chairman, T.U.C. Social Insurance and Industrial Welfare Committee and
Secretary, Agricultural Workers' Union

MR. H. COLLISON: I am very pleased indeed to have been invited to take part in this Twelfth Conference which has been organized by the British Occupational Hygiene Society. I must confess that when I counted up the list of speakers, I realized that we would all have to be extremely brief, and I am going to be that. You will find that I am dealing with one main point, although I shall mention one or two other minor matters.

Your aim as a Society, to build up better working conditions in industry, of course, vitally concerns the T.U. movement and other trade unions and, as Chairman of the T.U.C. Social Insurance and Industrial Welfare Committee, I personally find it immensely encouraging to be among so many of you who are devoting themselves to furthering this work.

The purpose of this conference is to discuss the need for hygienists in industry and the sort of training they should receive. You will know very much better than myself that this question of industrial hygiene and training involves not one element but many. It involves medicine, nursing, engineering, chemists, physicists and architecture; and, if I may say so, it involves co-operation of dedicated trade unionists and dedicated employers. We are fortunate here to be among people who have that kind of dedication. Although we here are in sympathy with each other, it is still true that this whole matter of industrial hygiene and occupational health is still, to some degree, a line of thinking foreign to people in some quarters.

I am having to do a great deal of looking at television just now. Last night, in "Panorama", we saw what was happening in Birmingham. It was explained to us that the old industrial quarters were being demolished and that new sites were being found for old industries. If you saw this programme and listened to the views of the older type of small industrialist, the very small employer, the man in the back-street factory employing perhaps three or four or six people, although you will have, as I had, great sympathy with him because these were the people who built up our tradition as an industrial nation and our tradition of providing a first-class product, you will appreciate that they had not the faintest concept of what we are trying to do. They had the concept that they were craftsmen—a very fine thing—but they had it in connexion with the family industry passed down from generation to generation, and they had developed their little industries in back-street workshops where conditions were appalling.

Therefore, I shall concentrate my short talk to you on the problem of the smaller industry, and I am not suggesting that everyone concerned with the smaller industry is as backward in thinking as I thought the people we were shown on television last night appeared to be. It is not my intention to talk about the actual content of the training programme. It would be impertinent for me to do so, because that is a matter for experts, for the doctors, for the engineers and the rest and, as you have

heard already this morning, in some of the larger industries, training programmes have been worked out.

I would make one comment about it: I think that it is unfortunate, and perhaps a reflection on commerce in this country that we so often have to go to America to get details of the kind of training which is needed. We should have done it ourselves. I am not going to try to intervene in this technical matter as to the type and content of the training; what I shall try to do is say something of what we in the Trade Union movement look for in an occupational hygiene service.

Firstly, the occupational hygienist, like every other worker in the whole field of occupational hygiene, has got to have first-hand practical experience of working conditions in industry. This can only be fully obtained with the active encouragement of industry itself. It cannot be obtained at all without access to industry. The speakers here this morning represent some of the biggest undertakings in the land and are convincing proof of the active encouragement which many managements are currently giving to occupational health.

On the other hand, it would be unrealistic to disregard the fact that in the bulk of our smaller factories (although they account for a very great proportion of the employed population) the need for occupational hygienists is still largely unrecognized. I would suggest, quite frankly and bluntly, that this problem of the smaller workplace is a real challenge to us all and is, in fact, a challenge to your society.

Much can be done voluntarily, I mean by education and by persuasion, and for this you have got to win the goodwill and confidence of both sides of industry. The example of what is being done by the managements represented here should be of real assistance and real encouragement in this direction. On the other hand, bearing in mind the problem of the smaller factory, I do not myself believe that voluntary action by itself is going to be sufficient. I believe quite firmly that responsibility rests upon the government to provide the general framework within which the contribution of occupational hygiene can be made available to the whole range of such industry. It is because of this that the T.U.C. attach such great importance to the pioneer work being done by the group health services for small firms operating at Slough, Harlow and elsewhere. I am very glad to see that, following me, we are going to have someone talking to us from Slough Industrial Health Service.

As you may know, the Nuffield Foundation has recently decided to put a quarter of a million pounds at the disposal of the Ministry of Labour for the development of similar group schemes elsewhere and of occupational hygiene laboratory services, and this undoubtedly is an encouraging development. But the ultimate aim must be to apply the lessons learned from the existing schemes at Slough and Harlow and elsewhere, and to apply them on a national scale.

As I say, I do not think that this can properly be done unless the government accept some responsibility for providing the basic needs.

I hope you will forgive me for what you may consider a diversion, but I am one who believes that, in this country, we have worked out for ourselves in the traditional British fashion of trial and error a system which is, or should be the envy of the world. We are living in troubled times and we are seeing a battle going on between conflicting ideologies. We have a mixed economy here and we believe that it works; I believe so, too. I think that the greatest asset any man can have is freedom, within reasonable limits. We have got to show that this thing works, and this demands co-operation, and I fully accept, as a trade unionist, that co-operation has got to come from all

quarters. Not only co-operation in the kind of thing we are trying to do but co-operation and understanding and a sense of responsibility towards national issues, so that one can see sectional issues in their right perspective. But that is a wider issue.

One of the things that we have got to show the world is the fact that our system works. This is important because so much that I am dealing with concerns our colleagues abroad and the developing countries. I am actively associated with the International Labour Organization. I have now followed Sir Alfred Roberts as a member of the governing body of that organization. I am President of the International Federation of Plantation and Agricultural and Allied Workers, and I know that we have got to show our friends that our system works. What we are doing here has got to be made to work. We do not want things imposed upon us but to develop them ourselves.

This means co-operation as between management and work-people and government, and I underline the need for government interest in this development, and government action, to ensure that we can extend our activities in this occupational health and hygiene field to the smaller industries which are largely now being left outside.

All this I suggest has an important bearing on the problems which concern you in the training of occupational hygienists. Until a proper system of health supervision for the smaller workplace has been organized, there is a danger, despite the sound understanding of environmental problems in workplaces where he is already placed by management, that the occupational hygienist will unfortunately have little experience where such things do not happen. This is a real problem so long as access to the workplace is dependent upon the goodwill of management.

I myself believe that a likely future development will be for trade unions to secure by negotiation with individual firms the opportunity of initiating expert investigation into the working conditions of their members. I believe too that the trade unionist, in places where industry is on a small scale, must be prepared to co-operate and exercise his influence towards the development of joint schemes such as we already have at Harlow and Slough. Agreements of the sort I have been talking about, in particular, agreements concerning large firms, have already been negotiated in the United States.

In the meantime, if, as I hope, training is to include practical experience of working environments in the small factory, this will have to depend largely on the persuasive powers of those responsible for training programmes. And in this connection, you will no doubt bear in mind that the results of persuasion are greatly enhanced by the care taken beforehand in explaining what is being done and why it is being done and why it is necessary to do it, to the trade unions no less than to the management. We want understanding on all sides.

The concern of the T.U.C. in this matter has been very clearly shown, and we are anxious to see that advances are made rapidly.

I was looking at your handbook which was published in 1958, and I read an introductory note given to you by Sir Alfred Roberts, my predecessor, as Chairman of the T.U.C. Social Insurance Committee. In 1958, he said this:

"As regards research, trade unions have for some time been urging the need for increased occupational health research and insufficient resources are being at present devoted to it. Too often, official assurance that there is no evidence associating a particular risk with occupation means little more than that the

necessary investigation has not yet been undertaken. We know little, for example, about the occupational incidence of chronic bronchitis and rheumatism; although recent small scale enquiries have confirmed a substantial excess of cases known occurring in some industries, we are still a long way from comprehensive statistics. Again, the introduction of new substances and processes into industry has brought new problems and hazards whose investigation calls for a wide range of expert skill."

That was in 1958 which I agree was not so very long ago, but we still find ourselves largely in the same position, namely of having to wait too long before a proper investigation is undertaken into industrial hazards, some of them old ones. For example, I am satisfied that rheumatism is a hazard in my own industry, in agriculture. It has not yet been proved.

I was very interested indeed to hear Dr. Swan talking about the hearing hazards in his industry. The T.U.C. has recently been conducting a survey into this question of industrial hearing hazards. We were told about it by associated unions and we made an enquiry up and down the trade union movement. You will be interested to know that the Musicians Union told us that, despite the development of modern music, they had no knowledge of any industrial difficulties occurring in their particular profession!

We are completely satisfied that this is an industrial hazard in many places and what has been said by Dr. Swan confirms this. We have asked the Industrial Injuries Advisory Committee to go into this question and conduct an investigation. I hope that it will be done quickly because I feel, and I think with some justification, that very often it is a question of shutting the stable door long after the horse has bolted. If we could only take more note of the things told to us by management and workpeople in their own industries, where they suspect there is a hazard, and if something effective was done more quickly with regard to investigation and enquiry, we would save a lot of incapacity and often a lot of death.

I do not want to finish without paying tribute to all those people who have been actively associated with this humane work, because it is a question of humanity, and not least our friends in the Factory Department of the Ministry of Labour. In the Movement, we do not think that the resources given to them are sufficient. We do not think the Inspectorate is large enough. They do a wonderful job of work and we recognize this and progress, despite the fact that it is slow progress, which is being made.

In my own industry, you may be interested, and perhaps pleased, with me to hear that so far as the members of my union are concerned—and we have some 125,000 agricultural workers in the National Union of Agricultural Workers—we have not had one death from toxic poisoning resulting from the use of poisonous sprays since we obtained information and legislation in order to make quite certain that protective clothing and protective equipment was provided, and since the industry has co-operated with the Government.

It is, I think, a credit to industry and in particular, Imperial Chemical Industries, for providing information which has made it possible to avoid these dreadful risks. Some years ago, we were shocked and staggered and worried because our people were, in fact, dying because of their contact with these sprays. We have, to a large degree, overcome this problem, although we still get minor cases of incapacity or ill-health, but people recover. This is an example of progress and what can be done.

Are we not justified, as a Trade Union Movement, in asking that measures of this type shall be injected into the whole of our industry, not only into the large industries where facilities are readily available and generously given, very often, by employers, but into the whole of industry, including the sector of smaller industry where money is short, where knowledge is non-existent, where training is the most difficult problem, and this is where your study today comes into it. Is it not important that we should insist always that the experiments at Slough and Harlow and elsewhere, which have been reasonably successful—indeed, I would say highly successful—are taken as a plan and a pattern for development elsewhere? Are we not justified in examining how the proper training to be given to individuals and the co-operation between doctors and nurses and engineers and the rest, can be brought into one content and applied effectively, so that these people all over the country can be assured of the help and protection and safeguards which they are entitled to have?

We have heard about ionizing radiations. I have talked about industrial advance. Certainly progress goes on. I find it rather halting and far too slow. Therefore, it is with very great pleasure and appreciation that I come to your conference today, thanking you for all you have done as a Society, thanking all those people who have shown this dedication towards an ideal. The T.U.C. are fully conscious of the importance of your work; we are fully conscious of the need for its development, and we quite sincerely thank you and all concerned with you for what you have already done. We wish you more than well in the future that lies before you.

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AN OCCUPATIONAL HYGIENE SERVICE

D. E. HICKISH

Director, The Occupational Hygiene Service, Slough

FIRST of all, I would like to amplify a little the type of industry which is being served by the occupational hygiene unit with which I am associated. For some ten years, we have provided an occupational hygiene service to the member firms of the Slough Industrial Health Service, which has already been mentioned. It is a group of some 200 firms ranging in size from 2 employees to nearly 2000. In this case, we have had the backing of a full and comprehensive medical service.

In the past three years, we have been extending our activities and have been providing a consulting service in occupational hygiene to firms anywhere in the country, and in this work, we have again covered a wide range of size of factories. We have ranged from small businesses in converted houses, businesses which in some cases have neglected the formality of registering themselves as factories, to some of the largest industrial groups in the country.

In this work, the medical services found in the firms visited have ranged from absolutely nil, through a part-time medical officer to firms with a full medical service. I would say that we are now an independent group from the Slough Industrial Health Service, and we will be carrying out investigations in industry by a consultant service, so my remarks will be flavoured by that background.

With regard to the need for occupational hygienists in this type of industry, we have received requests for assistance from a very wide range of organizations and industries. We have received requests from managements and trade unions. The factories we have visited have varied enormously in size and in type of product, but in every case, there has been a common link that circumstances have arisen in which the organization concerned has found itself faced with a problem with which it could not deal for one of three reasons. It may be a firm that has ample scientific staff but the firm will admit that they have not the experience in this particular problem, and they would therefore rather have it dealt with by people who have worked in that field. They may have staff who were experienced to deal with the problem but lack of time has prevented them turning that person over to the work. Or, in the case of the smaller factory, they have frankly not had the people with the training and ability to carry out the type of investigation needed.

I have put the function of the occupational hygienist in industry under three headings. First of all, he has the task of recognition of those environmental stresses associated with the work process, which may have an effect upon health; I will deal with that more in a moment. Secondly, he has the task of evaluating the magnitude of those stresses by instrumental means. Thirdly, he will be called upon to prescribe the methods by which any hazard may be controlled.

It has been our experience, as occupational hygienists, that we have sometimes been called upon to fulfil only one of those functions and, in other cases, to fulfil all three.

As examples of recognition, in the course of a factory survey, a firm was found to be engaged on the welding of a beryllium alloy without any idea that beryllium was a toxic material. Once this fact was brought to light, measures were taken. Evaluation: we have been called in by firms with medical officers to do a particular job. In one case, we were asked to assess the contamination of workshop air by oil mist in three different workshops, to enable the medical officer to go further into the cause of varied rates of incidence of skin trouble in those three workshops.

Sometimes we are asked for a prescription of control measures alone. We may be asked to advise a firm engaged in handling powders on the type of exhaust ventilation they should provide.

In other cases, we provide a complete investigation, where we start from the complaint and work right through to the control measures. The amount of detail required in the recommendations will, of course, differ greatly according to the type of firm. I think this is very important in the consideration of the training required by an industrial hygienist. If we are working in a large organization, we can very often make our recommendations in general terms, and there are adequate technical people within the organization, as has already been mentioned this morning, in the case of the Coal Board and elsewhere, for the recommendations to be put into practice.

In the small firms, we have to go very much further. We have to specify detailed sizes and designs for exhaust ventilation. We may have to design the actual lighting system which can be put out to contract and fulfilled.

Therefore, one of the things the industrial hygienist has to be able to do is give detailed recommendations for the control of the problems which he is investigating. Time and time again, when we are approached for investigations, a firm will say to us "Will there be recommendations at the end of your investigation? We do not want an academic investigation which will leave us in the same difficulty as we were before". Therefore, I would say that the industrial hygienist must be trained to give recommendations.

The time sequence of what we have been asked to do varies from the past to the future. We have been asked to look at past episodes, to reconstruct conditions which gave rise to complaint, illness or even death, and to see what the factors were. We have been asked to investigate processes which are at present in operation; and we have been asked to look into the future and examine new materials and new processes, and to look at plans of buildings and workshops, to advise on environmental factors.

The type of organization we have provided is probably somewhat different from that where a single industrial hygienist is working within an organization. For our consultant service, we have the following staff: we have a physician and an occupational hygiene engineer; we have a graduate analytical chemist; we have a medical laboratory technician who carries out urinary and blood tests. We feel that it is valuable for routine blood and urine tests to be carried out within an occupational hygiene organization where there are specialists able to consider the results of the tests in the light of the industrial conditions concerned. We find, too, that starting with blood and urine tests often leads on to environmental investigations and a solution of the cause of the problem. We also have a technician engaged on audiometry and other work concerned with noise problems.

We have found that being called in on an industrial hygiene problem has occa-

sionally shown to the firm their need for regular medical supervision, and an industrial medical service, often part-time, has been set up following our investigations.

With regard to training of occupational hygienists, I am entirely in agreement with the very valid point made by Dr. Swan, that the occupational hygiene organization is likely to meet resistance, particularly from the lower levels of management. There is a resentment sometimes latent that processes and ways of working are going to be criticized by implication in the report. If the occupational hygienist is going to retain the respect of those whom he may have to criticize, it is essential for him that, when he gives advice and makes comments, they should be soundly based, and I fail to see how he can do that if he has not adequate training and experience.

I would suggest that the training of an occupational hygienist should include first of all, physiology, some elementary industrial medicine and toxicology. This is not to suggest that the occupational hygienist is going to try and take over the work of the Industrial Medical Officer, but I think it is essential that he should know something of the function of the human body whose health he is trying to protect. I am assuming, of course, that there is medical advice available at all times. I do not see how the occupational hygienist can function without medical advice, because there are times when it is quite a problem to know what is the actual type of hazard and what is the type of investigation that should be carried out; e.g. if it is a dust whether it is toxic or is one likely to cause pneumoconiosis in one form or another. These are points where the advice and assistance and full co-operation of the Industrial Medical Officer are essential.

On the technical side, the occupational hygienist needs training in air sampling and analysis in its widest aspect. I include dust, radiation and noise. He should have a detailed training in heating and ventilation and air conditioning, because the majority of his control measures will be in that field. He should be experienced and have training in lighting. I think that it is desirable that he should also have knowledge of statistical methods so that he will be able to assess the significance of his findings. It is also essential that he should have in his training course some practical work and field surveys. This is common in the training courses in the United States, where during the course of training, the student visits factories, carries out a survey and prepares a report which is seen by his professor. His youthful enthusiasm is often tempered down by the remarks of his professor, so that he does not subsequently make the kind of mistake which would make him very unpopular in industry.

I think that there is need, too, for training for technicians in occupational hygiene as well as for graduates. We are concerned with a consulting service where we have to charge fees for the work we do and I envisage that this is going to be more common in the future. Economic considerations mean, very often, that the routine part of the investigation must be carried out by technicians under the supervision of the occupational hygienist, and I think that there will be a great need for training courses in particular industrial hygiene aspects for these technicians. I am thinking of courses in dust sampling and counting, so that a technician could be sent on the course and return, the supervisors knowing that he has a good training and is accurate in dust counting. Similarly, I think there should be courses in noise measurement and analysis, in ventilation testing, and the carrying out of thermal measurements.

I therefore suggest that there is a great need for industrial hygiene in industry of all types, and there is great need for training, perhaps on some of the lines I have suggested.

THE WORK OF THE FACTORY INSPECTORS

MISS K. CRUNDWELL

H.M. Deputy Chief Inspector of Factories

THE Minister of Labour in speaking in the House of Commons on 25th July, 1960, said that he was considering how best to develop industrial health services and that there was need for the fuller use and development of industrial hygiene services. At the same time he announced the grant by the Nuffield Foundation of £250,000 for the further development of group industrial health services and industrial hygiene services.

It will be seen that quite apart from their legal responsibilities in administering the Factories Acts the Ministry of Labour is closely concerned with what is being discussed here today.

During 1960 the Ministry published the booklet *Toxic Substances in Factory Atmospheres* in which maximum permissible concentrations are suggested for a number of materials. It was, and is, hoped that the publication of this information will stimulate employers to recognize the need for chemical, physical and biological testing in their factories. It is only by undertaking such positive testing that they can learn the actual atmospheric conditions in their factories and the effects on their workers. It is, for example, only by finding out how dust or fume is escaping from a process, in what direction, at what speed and in what volume, that there can be any certainty of controlling it. In more than one process recently we have learned by means of improved techniques for observing the behaviour of dust that exhaust ventilation previously thought to be adequate was in fact not preventing the escape of fine dust into the workers' breathing level.

In the expectation, or at least the hope, that the demand for testing facilities will be stimulated, a Sub-Committee of the Industrial Health Advisory Committee, a committee set up by the Minister of Labour to advise him on matters relating to industrial health, has been trying to find out what testing facilities in fact exist.

There was thought at one time, of publishing a central directory of such facilities. That at the present time is not considered practicable but it may be possible through the Divisional organization of the Factory Inspectorate to get to know of local facilities for different kinds of testing, e.g. dust sampling, in the main industrial areas and to have a record of these so that an employer needing a certain type of service can be told where he may be able to obtain it.

A rather bigger problem may however prove to be to convince industry of the need for testing, and to convince them to such an extent that they will be willing to use services which may be quite expensive. We may, perhaps, expect large firms to accept this proposition but the smaller man may well be a tougher job to convince. It has been suggested that many will not take kindly to the suggestion that they should pay in order to provide, as they may see it, the evidence on which to hang themselves.

There are of course many employers who are anxious to improve their working

conditions if they can be shown the need, but there are others who will do no more than they are forced to do.

It may be wise therefore not to expect a very rapid development in the demand for industrial hygiene services. How are we to set about convincing employers of the need for this positive testing? The first answer to most people will probably be through the Factory Inspectorate but apart from the fact that the Inspectorate is already heavily burdened, it is the enforcing authority and the Inspector's advice on this matter may not always be acceptable. Some additional approach will have to be thought of.

On the other hand, I heard only yesterday from a colleague that over the last few months there has been an appreciable increase in the number of firms who have themselves started to carry out atmospheric tests—the firms instanced were those who themselves had laboratory facilities. One firm which had under guidance from the Factory Inspectorate started to do their own testing had now handed it over to the Slough Industrial Hygiene Service.

I thought that you might now be interested to hear how the Factory Inspectorate works to solve a problem which might well be one suitable for an industrial hygiene team if one were available. This particular problem was one which came up last year.

Some of you will know that in addition to the general Inspectorate responsible for the general administration of the Factories Acts, there are the specialist branches of Medical, Chemical, Engineering and Electrical Inspectors. I am not today concerned with Electrical Inspectors. The roles of the other three branches, Medical, Chemical and Engineering are distinct though interdependent.

Now to come to my particular problem.

There is a process by which coloured transfers are made. Sheets of paper are printed with the transfer design and treated so that the dry colour when it is applied adheres where it is wanted and not to where it is not. Dry powdered colour is fed to colouring machines and when the sheets are put through the machines the powdered colour is dusted on to them adhering where it is wanted. Surplus loose colour is subsequently removed in other machines where the sheets are cleaned with sharps or fine sawdust. The colour is finely ground and contains lead and there is quite a serious risk of lead poisoning if the colour escapes into the breathing atmosphere of the workers.

Most of the factories doing this process are concentrated in one area. A case of lead poisoning occurred in one of these factories. This led to a close consideration by the District staff of the traditional methods of applying exhaust draught to both the colour dusting and cleaning machines in all these factories. Certain improvements were made and the Chemical Branch of the Inspectorate was then asked to carry out extensive lead-in-air estimations in the factories to see whether working conditions could then be considered safe. At the same time it was decided that it would be advisable for the workers exposed to the lead risk to be examined for lead absorption. The pathologist member of the Medical Inspectorate visited the works and took urine and blood samples for examination. These showed that a number of the workers exposed were suffering from some degree of lead absorption. It was also quite clear from the chemical testing of the atmosphere that proper control of the lead dust had not yet been effected.

It was interesting to find that the biological coupled with the chemical testing,

pointed quite clearly to the areas and jobs where the main hazard lay. Having located these it was possible to set about dealing with them, if necessary, with the advice of the ventilating experts in the Engineering Branch of the Inspectorate.

A further interesting development is that it has been arranged for checks on atmospheric conditions in these factories in the future to be made by the local College of Technology.

I hope that I have made it clear that the Ministry of Labour needs no convincing of the value of the work of industrial hygienists and that within the Inspectorate there is an example of the way in which a team of specialists can and do work together to improve working conditions.

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AN INDUSTRIAL MEDICAL SERVICE

J. G. FORTUIN

Director of Medical Services, Messrs. Phillips, Netherlands

I THINK that I can best start by introducing my company, Phillips, in Holland, employing some 78,000 people. About half that number work in Eindhoven and the other half is scattered over some fifty other smaller and larger factories ranging from several hundred people to several thousand people.

The products are quite numerous: incandescent lamps, fluorescent tubes, radio and television sets, and all other types of electronic equipment; also, insecticides, pharmaceuticals, gramophone records, X-ray equipment. And for all those things we have a number of other factories to make our own components such as glass works, machine shops, metal works, paper mills, a large building department and large laboratories. The head office of the Medical Service is in Eindhoven but we also are responsible for the industrial hygiene in the other larger and smaller plants in our country.

Perhaps it will interest Mr. Collison to know that we try to have a full-time Medical Officer also in the smaller plants, and have succeeded by combining these plants with other smaller factories in the same town. In the first phase, we run the show and they can profit from our experience, from our equipment and from our technical personnel. We expect that, after a few years, they will become independent of Phillips; nevertheless, we hope that there will be a link between Phillips and these independent local industrial services so that we can still pool our medical equipment for measurements, because it may be very expensive, and it may be useful to pool this medical equipment in one central place.

I am the eighth speaker this morning so I expected that something that I intended to say has been said before. I propose to make a number of statements—about 5—with some comment, and this will more or less represent my views on training for industrial hygiene.

It is the task of the industrial medical service to check working conditions in the factories, laboratories and offices, to evaluate the findings in terms of health hazard or discomfort, to give advice to the management when improvement of the working conditions is considered to be necessary, and to check the result of such improvement. Checking environmental conditions is often left to a more or less independent industrial hygiene department that is quite separate from the medical department and, as far as I can observe, co-operation between those two departments is not always very close; so, in my opinion, it is a task of the medical department.

This statement does not imply that the industrial physician should perform all these activities personally, but there is one item in this series that belongs exclusively to the province of industrial medicine, namely the evaluation of the results of hygienic measurements in terms of health hazard. It is only the medical man who can evaluate the results.

This evaluation is more than just comparing the result with the corresponding MAC value, if such a value is available. A number of complicating factors have to

be considered. For example, the concentration of noxious material in the air may vary in the course of the day, and short exposures to high concentrations may cause a biological effect different from that of long exposures to low concentrations. There is a number of other factors which I will not mention now, but it is true that our knowledge of how to take all these factors into account is still defective. This fact only confirms my opinion that only the industrial physician can take the responsibility of deciding whether a working condition is safe or not. He can at least estimate the expected biological reactions and he cannot leave this decision to an engineer or chemist. This statement is more less a reaction to what I observed in the United States.

The measurement of hygienic conditions, for example, the concentration of toxic vapours in air, requires a technical and chemical knowledge that is outside the scope of the training and practical work of an industrial physician. Here he needs the co-operation of an industrial hygienist, preferably a chemist of graduate level. On the other hand—and this has been said before this morning—the industrial hygienist needs the doctor's indications as to the specific questions to be answered by the results of the measurements.

Sometimes the problem requires the determination of the average concentration over a long period of time and, on other occasions, we are especially interested in the occurrence of peak concentrations of short duration. Which method is to be preferred depends on the nature of the medical problem, and the exact formulation of the questions by the industrial physician is the starting point for all further activities. The choice of the appropriate sampling device and analytical technique remains the responsibility of the industrial hygienist.

A well-founded evaluation of the results of hygienic measurements requires complete information on the circumstances during the sampling or measurement. The report should contain not only the results and an indication of their accuracy, but also all the factors that may contribute to the evaluation of the hazard. A verbal discussion between doctor and hygienist on the results and the accessory circumstances is absolutely essential.

It may be very important to know whether the concentration of an air contaminant was determined on a cold and windy day when all doors and windows were kept closed, or on a hot day with all the windows open. It is also necessary to check that during the sampling of air the production process goes on in its normal way and at its normal speed. Often the workers try to give some show, either in one direction or in another direction.

The chemical techniques adapted to the requirements of industrial hygiene problems are often quite different from the analytical methods used in other fields of chemistry. The control of health hazards in industry requires chemical techniques with a very high sensitivity, whereas a moderate accuracy is usually sufficient for the purpose. We have had experience of co-operation with our chemical laboratories but they were not satisfied until we had reached accuracy within a limit of one per cent, so the final result was not satisfactory. It does not matter so much if there is 80 or 90 p.p.m. in the air. As a standard, we require of our methods that one-tenth or one-fifth of the MAC value can be detected.

When improvement of the hygienic conditions is considered to be necessary, the management should be informed not only of the urgency of the improvement, but also of the technical changes that are expected to reduce the hazard to a safe level.

It is certainly insufficient to tell the management that at a certain spot in the works the concentration of a toxic vapour exceeds the MAC value and leave it to them to find out the best way to improve the situation. The technical advice concerning the improvement is not a task of the industrial medical service, but the industrial physician should take the initiative in a discussion on the matter between the doctor and the chemist, on the one side, and the engineers interested in technical hygiene on the other side. In my opinion, this is the only way to make sure that the technical measures to be taken will result in safe working conditions and will cost no more money than necessary.

Summarizing, we may say that, although the industrial physician is responsible for the working conditions as far as they may include chemical or physical hazards, he needs the co-operation of a chemical expert for the diagnosis of the situation and of a technical expert for the treatment to be advised to the management.

Following these lines the Phillips Medical Service in the Netherlands gradually built up rather a simple organization, of which the so-called Technical Hygiene Committee is the centre. Members of this committee are the chief industrial physician, who is the chairman; two other industrial physicians with special interest in toxicology and physical hazards; the head of the Safety Department, who is an engineer; a chemist, who is the secretary of the committee; and a pharmacist, both belonging to the Medical Service; two engineers, both belonging to the Technical Service Division and in charge of the environmental conditions in the works. There are therefore three engineers, a chemist, a pharmacist and three doctors. With one exception, all members are university graduates.

In the weekly meetings of the committee the chemist presents the results of the measurements performed in the preceding week with all the relevant additional information—windows open or closed etc. If the committee concludes that technical improvement of the situation is necessary or desirable, the engineer members are asked to consider the problem and to give technical advice at the next meeting. All the pertinent data, the conclusion of the committee and the technical advice are then handed over to the industrial physician in charge of the department concerned, who will discuss the matter with the responsible manager.

The second task of the committee is to consider the new requests for measurements from industrial physicians or factory people. The purpose is the exact formulation of the questions to be answered by the measurements. That makes quite a difference; you should never start to measure something because you have the equipment. I am speaking from personal experience.

The third item on the agenda is the questions laid before the committee concerning the toxicity of substances considered by development departments for future use.

There is another item: when new buildings are on the drawing board, all the drawings are laid before the committee for their advice on ventilation, heights of rooms, etc.

There is an auxiliary staff, headed by the chemist and consisting of two technical people who take their air samples following the instructions of the chemist, and two chemical analysts working in the Industrial Hygiene Laboratory, which is part of the Medical Service. I have confined myself to chemical hazards and dust in the air, but the same procedure also applies to ionizing radiation and to noise, only the central committee consists of some other people.

In my opinion, there is a need for chemists and engineers—chemists for the diagnosis, engineers for the treatment—trained in the field of industrial hygiene, qualified for their responsible job in modern industry and willing to co-operate with the industrial physician without taking over his responsibilities in the field of health care and preventive medicine.

As the usual university programme for chemists and engineers in my country does not include the specific theoretical and practical problems of industrial hygiene, post-graduate courses must be organized for this purpose. In my opinion, the best starting point is not a course which includes all the items that have been mentioned this morning, which would last probably two years, but to start with a short colloquium where people who are more or less experienced by trial and error could exchange their experiences and learn from each other.

DISCUSSION ON THE MORNING SESSION

MR. P. C. G. ISAAC (Kings College, Newcastle upon Tyne) said that the need for men trained in occupational hygiene is emphasized by the difficulty of obtaining skilled advice in this field. Recently the Industrial Health Advisory Committee of the Minister of Labour has been concerned with the availability of testing facilities for the assistance of industrial medical officers and industry generally.

At the instance of a subcommittee of the IHAC PROF. SCHILLING *et al.* (1960) carried out an inquiry among members of the Association of Industrial Medical Officers. This was concerned with three kinds of tests: (i) biological, (ii) environmental, and (iii) suspected hazards; it did not cover the wider question of occupational-hygiene control and design. It showed that the great majority of industrial medical officers required one or more of these tests to be carried out, and that a proportion, about one-third in the case of environmental tests, could not get at least one test done. Some tests were carried out within the M.O.'s own organization and some by outside bodies or individuals. Nevertheless, even of those M.O.'s who were able to get tests done a majority would have used an industrial-hygiene laboratory, if this had been available. This seems to emphasize the importance placed by the M.O.'s on the independence and experience of the testing laboratory. Many of those M.O.'s who were able to get tests done outside their own organization found that much time was spent in seeking this outside help.

Following Professor Schilling's inquiry and the report of the Sub-Committee the Ministry of Labour set up the Industrial Hygiene Services Panel "to advise on the compilation of information about available services for chemical, physical and biological testing in factories, and on how to ensure their fuller use."

In the summer of 1960 the Ministry approached interested Government Departments, Industrial Research Associations, Universities and other organizations to find out what testing facilities were, or could be made, available to industry. The kinds of test concerned were chemical, dust, general environmental conditions (including certain engineering design), radioactivity, and pathological, biochemical and radiological.

The inquiry elucidated a great deal of information, most of it singularly unamenable to classification or generalization. Quite wide interest was shown, and this was a cause for hope, but it was clear that only three organizations, namely Slough Industrial Health Service, North of England Industrial Health Advisory Service (University of Durham), and Nuffield Department of Occupational Health (University of Manchester), aimed at providing a comprehensive occupational-hygiene service and the Panel felt no hesitation in drawing them to the attention of Industry.

A number of Government departments have testing facilities which are in most cases fully occupied and could not be made available to industry; DSIR laboratories are engaged on research, though some testing facilities are available from the N.P.L., N.C.L. and Warren Spring Laboratory. MRC units, too, are concerned with research and could not normally undertake routine testing. The majority of Industrial Research Associations can carry out some tests, but usually only for their own members.

Various kinds of tests can sometimes be carried out on an *ad hoc* basis by university and technical-college departments, and by hospital pathological laboratories. The panel, however, felt that most occupational-hygiene tests require considerable skill and experience if their results are to be useful, and, further, that many M.O.s require a professional opinion as well as a simple numerical result for the non-biological tests. Neither of these desiderata is met by the piecemeal carrying out of *ad hoc* tests, although until a wider service is built up such tests may be better than nothing.

In short, the Panel's inquiries so far have served to emphasize the need for trained personnel skilled in occupational hygiene. And, if I may interject a purely personal opinion here, it does seem to me that this skill needs to be possessed by the medical man as well as by the layman, to whom we seem to have directed our exclusive attention in this Conference. Part of the strength of the system of training in this subject in the United States lies in the fact that medical and non-medical post-graduate students sit down together in lectures of common interest and work together in laboratory periods.

I should like to thank the Safety, Health and Welfare Department of the Ministry of Labour for allowing me to make use of some of the results of the inquiry carried out for the Panel and for looking over my note in MS.

DR. DIXON (Esso Petroleum, Milford Haven) said that various speakers, including representatives of the trade unions and of the Ministry of Labour, had pointed out the difficulty of educating the small employer to appreciate the need for good industrial hygiene. The tremendous popularity of medical programmes on television, which had been mentioned in leading medical journals and in the national press in the last few weeks, had overcome many of the criticisms which were originally voiced about television programmes on that sort of subject. Even among their own conservative profession, he suggested that the Society might well approach the television authorities directly to encourage the presentation of programmes on industrial hygiene subjects where the educational pills could be buried in the sugar of drama.

He suggested that that medium would stimulate the worker to take an interest in his own environment because, in many instances, the worker was as much to blame as his employer. He did not appreciate the dangers in which he was working, and did not see the necessity for their improvement. It would also educate the smaller employer to appreciate the need for industrial hygiene services.

With regard to the cost of industrial hygienists, the last speaker had mentioned that certain official organizations like the D.S.I.R. were willing to carry out specific investigations. His company had asked them to do a noise survey for them at Milford Haven Refinery. They had said that they could not do it for six months and it would have cost several hundreds of pounds. Their own industrial hygienist was able to carry that work out within a week or two and saved a large proportion of the annual salary within two or three days. That was a point which certainly told well with his manager in that case.

DR. HAYDON (British Railways, Southern Region) said that the problem must be a national one. He would like to see something set up on the lines of a public health laboratory service which would be available to industry. In his opinion, the amount of money needed would be saved in a year or two by the prevention of accidents and industrial hazards generally, but the trouble was the initial cost. If he

were to employ Dr. Hickish, he had to pay him and therefore had to justify to his management the amount of money to be paid to him and unless the problem was a real and actual one, he would not get the authority. He had had enormous help from the Factory Inspectorate, both the Engineering and Medical sides, but one knew that they were grossly overworked, and one could not put a problem to them unless one felt that it was going to be of interest to them. Therefore, he thought that it should be a Government responsibility, and it should be free to industry just as National Health itself was free.

PROF. R. C. BROWNE (Nuffield Professor of Occupational Health) said that what was really being debated at present was whether the cost should be borne by the firm asking for the advice or whether it should be borne by public funds.

It was true that small firms needed more advice than big firms, but they did not demand it and if, for example, 160 firms of different sizes were circularized, it would be found that 10 per cent of them would join the service and they would nearly all be big firms. Very few of the small firms would answer the letters. Quite a lot of them would not answer even when a stamped and addressed envelope was sent. He did not think his experience was any different from what would be found in any other part of the country. They had got to think around the possibility of producing some kind of financial persuasion to the small firms to use the services. One of the reasons why that worked so very well in parts of the United States was that the firms which did not use it got their premiums loaded for insurance. He was sure that was one of the big variables which helped them along.

With regard to the working together in industry of the occupational hygienist and the doctor, he had never yet dared to countersign an estimation carried out by his occupational hygienist; he would try that next week and would report back—unless there was an explosive reaction at some later time. It seemed that there was a symbiosis there; that was essential and he thought if it could be arranged so that the doctor and the occupational hygienist both took orders from the other when the other was off his guard, that was the kind of relationship to aim at. Occupational hygienists and doctors could not be trained in the same course. There had to be quite separate courses. It was a good idea to think along the lines of a course for doctors entitled something like "Occupational hygiene—what it is and how to use it" but that, of course, had to be quite a different type of instruction from the sort they were at present discussing.

DR. J. STEEL (Department of Industrial Health, the Medical School, King's College, Newcastle) said that, in his excellent paper, Dr. Hickish had outlined the functions of the occupational hygienist as, first of all, to establish whether or not a hazard existed; secondly, to estimate the extent of the hazard, and thirdly to suggest methods of eliminating or mitigating the effects of the hazard. It was with the third function that he wished to deal because Dr. Hickish had given as an example the design and detailed specification of exhaust systems. He himself wondered, in fact, whether it would not be more economical in time and labour if the occupational hygienist, in that particular case anyway, gave a broad specification so that the recipient of the information could then approach a firm which specialized in that world and might, in collaboration with the occupational hygienist, design such a system which could then be further tested by the occupational hygienist who would keep on testing it until it worked. He thought the design of exhaust systems was

highly specialized engineering, and he knew that Dr. Hickish had that specialized knowledge, but he doubted very much whether more than a small percentage of trainee occupational hygienists would have it. He thought that the provision of such a training was beyond the scope at the present time of a course for occupational hygienists. Perhaps Dr. Hickish could comment on that.

DR. D. E. HICKISH (Industrial Hygiene Engineer, Slough Industrial Health Service) said that obviously, on a large installation it would be a waste of time for the occupational hygienist to do detailed design of ductwork. He was thinking in terms of the small firm which had small plant. It might be necessary for the occupational hygienist at least to specify sizes or volumes and, in small cases, it might be necessary to guide the people on the actual size of fan ducting, in simple cases.

Very often, occupational hygienists would be concerned with the malfunctioning of the existing system. That was an important point. It was the practice in the training courses in the United States for sufficient information and instruction on exhaust ventilation to be given for the trainees to design a complete exhaust ventilation system from start to finish, on an actual installation. That was one of the Final Examination questions. It was important that the occupational hygienist should have that knowledge. There were many poorly-designed systems and he had to be able to put his finger on the spot in any particular system which was not functioning. He agreed that in most cases he would specify the performance and check it rather than detail sizes and so on, but he thought the knowledge should be there.

MR. MACDONALD (Ford Motor Company, Dagenham) said that his first point had been made in different ways by Dr. Whitehead and Dr. Fortuin. It concerned the question of courses, without trespassing on the afternoon's session.

A lot of those present worked in industries where, as both had said, there were people who were experts or partial experts in the processes which took place in their industries. They had chemists, they had engineers, they had research departments, to which they could appeal. At the same time, there were things, particularly methods of installation, that they were not familiar with; he felt that there was considerable advantage to be gained from following up Dr. Fortuin's suggestion of holding a colloquium where people could meet and discussion take place, rather on the lines of the present conference. There could be a short course, not nine months or even three months, to which people could be sent who already were fairly well trained or, in some cases, very well trained in certain subjects, and at which other people who were better trained could give them information, or at which information could be exchanged. That was a way in which a large step forward could be made with comparatively little loss of time.

His second point concerned small factories. There had been talk of small factories; there were also small units of large industries and he thought that they could do more through some of the trade associations. He had in mind the Medical Panel of the Council of Ironfounders Association. This trade association, sponsored a survey of small foundries in the country, and produced some interesting information. At the moment, a survey was going on in some of the larger industries employing a considerable number of foundry workers, and there was a project, which was not far off, whereby a survey could be done and action taken, not just an academic survey, of all the small foundries of the country.

He wondered if in other industries there was not an opportunity for working with trade associations who, after all, had far closer links with their smaller members

than with some of their larger members. In fact, in some of the trade associations, the very large people did not belong but worked in very close co-operation.

He thought that there was quite a field in this country that could be covered through trade associations.

DR. DAVIES (London School of Hygiene), returning to a point raised by Drs. Steel and Hickish said that there had been a little latent criticism of Dr. Hickish's ambitious programme for training industrial hygienists, but he thought that it arose from a misconception of what had been meant. To bring that point out, he told the story of a factory in which he had been interested, where a very large and complex plant inside a large building created considerable trouble both within and without through emission of formaldehyde. Formaldehyde was poured into the apparatus at one side and came out at the other end, and the difference between went out to create a nuisance. The function of the hygienist in that case was not, as some people believed, to concern himself with the detailed engineering of ductwork but to put his finger on the fact that the chemical engineers on the process could provide information upon the difference between the formaldehyde that went in one end and out at the other. It was on the difference that the ventilation system had to be designed.

That was really what Dr. Hickish had been getting at; that the industrial hygienist's concern with such detailed matters as ductwork, etc., was not that of the specialist who was going to design the architecture of the system or work out details. It was much more than that. It was a typical commonsense attitude to the fundamental issues which, in his own experience, were frequently overlooked by the specialist firms who would put in ventilation plants with no consideration of the amount of toxic product which was to be handled.

DR. J. M. ROGAN (Chief Medical Officer, National Coal Board) said that he had been struck, during the course of the morning, by the fact that although various views had been expressed by various speakers, there was a fair measure of agreement between them.

As far as large establishments were concerned, there must be general agreement that, by and large, the occupational hygiene service provided was not too bad, and that there was already, in those concerns, a large body of expertise which could receive more training with advantage.

The real problem lay with the small establishments. Obviously, the only way of providing adequate occupational hygiene services for the small factories was by a system of grouping.

He did not think there could be an adequate service unless a reasonable career could be offered for the occupational hygienist; otherwise, they were simply indulging in wishful thinking. The only people who could offer such a career were the Government. Why did the occupational hygienist mean something in the United States and not in this country? It was because the American Government had quite firmly established a cadre of occupational hygienists which had considerable standing.

Returning to Dr. Fortuin's point, occupational hygienists could not work in isolation; they had to be in close association with medical men. As yet, there was no trace of a general occupational hygiene service for small factories. He was quite sure that, contrary to present Government policy, this could not be left just to grow up in the hope that an enlightened employer here and there would do something.

He suggested that the £250,000 provided by the Nuffield Foundation was very

encouraging, but a drop in the bucket. One had to think in terms of millions. Although that could not be justified in terms of immediate economic gain, he was sure that the intangible gain would be enormous.

On the cost question, and where the money should come from, the only way of providing it was directly or indirectly by the State. Employers, workers and taxpayers might contribute something. Some such system had to be brought into being.

They had heard quite a lot about the Ministry of Labour. He had a high admiration for what the Ministry of Labour had done, but, after all, they had had the responsibility of occupational health for very many years, and they had heard that morning that the Ministry was still labouring under the difficulty that they could not possibly meet the demands which they were already receiving from industry, although the potential demand was greater. Occupational health should be placed fairly and squarely where it belonged, under the Ministry of Health, in spite of the fact that the ministers, with one notable exception, had shown little or no interest in the subject.

DR. J. G. FORTUIN (Messrs. Phillips, Netherlands) said that he did not completely agree with the solution that industrial hygiene problems should be paid for from the outside, for instance, from public funds. He thought that factory people should be educated in such a way that the machine in the process did not only aim at production but that production included waste disposal, and waste disposal was not a special problem to be dealt with by other people. Also, safety and working conditions were not problems to be dealt with by other people but were essentially parts of production.

Regarding cost, it was sometimes very useful to express cost as a percentage of some very large figure, such as total annual waste.

DR. CHALLEN (Slough) said that it was a little unfortunate that Dr. Fortuin had spoken before him because some of his remarks were directed towards Miss Crundwell's points. He was happy at the meeting until Miss Crundwell gave her paper and then he had become extremely depressed because it seemed to him, though he might be interpreting her paper incorrectly, that, as representing the Ministry of Labour, she was extremely lukewarm with regard to the future of industrial hygiene and industrial health.

For the last three years, he had had the extra function of publicity officer for the service, writing to trade organizations and research organizations and a variety of firms, etc., to interest them in the service and the use of it. It was extremely hard work, very depressing and unrewarding. He had come to the conclusion that the Ministry of Labour was all important, particularly factory inspectors and lay factory inspectors. He suggested that it might be advantageous to run very short courses in the three university departments for lay inspectors to acquaint them with the functions and value of an occupational hygiene service, because he did not think many of them appreciated the use and the value. It was important that, in the future, the factory inspectorate should send problems into the laboratories that were going to be available. Secondly, he hoped that, in the future, they would not refer routine testing to technical colleges. He did not think the samples were of very great value and it was obviously necessary to repeat them. What was more important was accurate and repeated biological testing.

Lastly, there was a great lack in this country of facilities for *ad hoc* toxicological research testing of new products. He knew from a number of firms that they would

use such facilities if they were available. It could not be expected that the toxicological research unit should deal with all the *ad hoc* problems, which were increasing with the increasing number of complex chemical substances.

DR. M. L. THOMSON (London School of Hygiene) pointed out that there was a course for inspectors of factories at the London School of Hygiene in the Applied Physiology Department.

PROF. R. C. BROWNE (Nuffield Professor of Industrial Health, Newcastle) said that experience in the North had been a little different. The greatest co-operation and help had been given by Medical Inspectors of the Ministry of Labour in his area, and they were to be found in the Department almost every week. He did not know whether that had some connexion with the fact that the Medical Inspector and the Professor came in on the same train in the morning, but he did not think it was only that.

MR. H. COLLISON (Chairman, T.U.C. Social Insurance and Industrial Welfare Committee) made a comment about the problem of the smaller firm. He was a little unhappy because there was a vagueness about the discussion and a lack of determination. He pointed out that certain things were quite obvious, on the face of the matter.

The representative from the Ministry of Labour had said that it was going to be awfully difficult to get the smaller employer to pay for the service. He knew that that was true. He knew too that, where group schemes had been in existence, a lot of the smaller employers passed them over. They did not want to participate in them. Therefore, if it was regarded and accepted as a social service as well as being an industrial service; in other words, if one accepted that it was something which society had got to inject into industry as a social measure, one had to look at the situation which then developed. Was it simply going to be left that, if the smaller employer did not want to, or could not, pay for it, one just stopped there? That was why he was rather perturbed about the situation.

One or two things could be said in addition to that in connexion with the ability of the smaller employer to pay. Possibly, if he understood that certain savings were involved, he might consider what it cost him against what he saved by it, and find that he might profit out of it at the end. That was a purely industrial motive. But if it was found that, by the development of group schemes by other hygiene services and occupational health services, some things became socially necessary in industry and certain factories (certain equipment ought to be put into a factory), it would be found eventually that such a requirement (and he hoped to see it written finally into the Factory Act) would mean that if the smaller employer could not do it because of financial reasons, he would be pushed out.

That had to be decided in relation to the social issues involved. Speaking personally, he believed in freedom for people within certain limits, and he would not want to see a large number of small employers pushed out because of the extra cost involved.

That led to the conclusion that it had got to be a question of co-operation as between employers and the State. The State had a responsibility to find means whereby those things could be done, where it was socially desirable that it should be done, and it was also socially desirable that small enterprises should be allowed to continue to exist and to come into existence; it was clear that the State had to look at it again and do something about it.

He had said when giving his talk that he greatly appreciated the things that were being done; within its power, the Factory Department was doing a wonderful job, but he wondered whether enough was being done. He agreed with Mr. Isaac when he spoke about the problems of hygiene laboratories to which people could go. Welfare Officers were saying that they could not get the test done that they wanted done, and they ought to be able to, and who was going to provide the means. That was a question which had to be sorted out and sorted out quite thoroughly. The question as to who carried the burden, and who did the job, as divided between employer, worker and government, had to be determined, but he could not see it being determined by the exclusion of government and by throwing the whole burden upon enterprise, particularly the smaller enterprise.

REFERENCE

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OCCUPATIONAL HYGIENE COURSES IN THE UNITED KINGDOM AND OVERSEAS

C. H. WOOD

London School of Hygiene and Tropical Medicine

WHEN our past president asked me to collect information on the courses available in this subject, he first asked for those in the United Kingdom and then added, "and overseas", just in case there were none at all! By throwing in overseas, the scope really becomes very wide and I am therefore going to limit it in two ways. Firstly, I shall limit it to courses which may be suitable for people from this country and, owing to our national habit of not speaking foreign languages, I shall exclude all courses other than those held in English. This really means courses in this country and in North America. This is a pity because there is no doubt that in certain countries in Eastern Europe, in the Soviet Union, in Yugoslavia and Czechoslovakia, there are fairly extensive occupational hygiene services, and their training programmes might be of interest. The other limit I am going to place on the scope is to exclude basic courses for those who, when starting this specialist study, may come from the fields of engineering or chemistry or physics. Clearly, if they do come from one of these fields, they may have a certain amount of basic groundwork to do in the other fields. This I feel is outside the scope of what I am trying to talk about.

It is common knowledge that there is very little in the way of occupational hygiene training here. On the other hand, it is well known that, in the United States, there are a number of institutions running courses of varying length and comprehensiveness. Some of these courses last for a year. Some are shorter. I do not want to go into the details of these individual courses or to make any comparison between them except to say that your President-elect, Dr. Hickish and myself have attended the best one, at Harvard.

The principal subjects in all these courses are summarized below:-

<u>Measurement and Control</u>		
<u>Hazards</u>		<u>Comfort</u>
Gases	Heat and Cold	Heating and ventilating
Mists	Pressure	Lighting
Dusts	Noise	Machine design
Atmospheric pollution	Radiation	
Industrial wastes		
<u>Physiology</u>	<u>Toxicology</u>	<u>Industrial Diseases</u>
Temperature regulation	Mode of entry and action	Pneumoconiosis
Fatigue	Dose response	Dermatitis
		Deafness

Statistics and Epidemiology-Industrial Background

I would say that the meat of all these courses comes in measurement and control. The sub-headings are merely a list of the things Dr. Hickish and others mentioned this morning. I have divided them into two groups, hazards and comfort, which I consider rather in the same way as curative and preventive medicine. They are clearly very closely linked but hazards are the sort of problems you are asked to deal with while comfort may be the field in which, ultimately, more time will be spent.

Apart from the main backbone of the course, another important section is physiology, toxicology, industrial diseases. This, as Dr. Hickish said, is not meant to infringe on the scope of the industrial medical officer, but it is, for example, rather difficult to investigate heat and cold without having any understanding of the body's temperature regulation mechanism.

In the field of toxicology, most of it is again the province of the industrial medical officer, but to control gases, dusts and fumes, one needs to have some idea of their mode of action and the problems due to variations in individual response.

Again, industrial diseases, elementary knowledge of such things as pneumoconiosis, dermatitis, deafness, is required.

Epidemiology is another basic science which, irrespective of whether students come to the field from engineering, chemistry or physics, they tend to lack. This is therefore taught in all the courses.

What I imply by the heading industrial background, is some knowledge of industrial processes, industrial organizations, industrial law and that sort of thing, which is included in these one year courses.

To turn to the United Kingdom, what do we have here to match this? I tried to look at this from two different angles. Firstly, I asked the employers of occupational hygienists where they would get them trained. This included asking one or two of the nationalized industries, private industrial research organizations and a Ministry. The answers were surprisingly similar considering that they came from such diverse organizations. The only training that is done is an in-service training augmented, in some cases, by short courses generally run by the senior staff of the organization. I asked each of these people whether they ever took outsiders into their training programme. The official answer was "no" but it was quite clear that visitors are often accepted for short periods. It is also clear that one of the large nationalized industries interested in dust control trains a considerable number of technicians which it then underpays, thus providing a cadre of trained technicians for more profitable organizations.

Secondly, I made enquiries about training from training establishments. I tried to find out from universities, from colleges of advanced technology, from technical colleges and from national colleges of technology. These national colleges are created when the industries to which they relate are so scattered that they have come together to run one institute. The National College of Heating, Ventilating, Refrigeration and Fan Engineering, based on the Borough Polytechnic in London, is an important example. I tried also to find out about training from the many Trade Research Organizations. One thing about trying to find out anything from all these is that it is extremely difficult.

It is possible to find something out if you go on long enough, but I think it is virtually impossible for a would-be recruit to occupational hygiene to find it out for himself if he did not already know about the subject he was meant to be studying, before he started.

For example, this is the sort of difficulty: London University provides no comprehensive list of the courses that it runs. You can get a list of the schools, and if you apply to each individual school, you can find out what courses they run. But who would think that places like the College of Estate Management run courses in public health engineering. When you ask the University for a guide to its courses, you are referred to the London County Council, who produce two pamphlets—*Floodlight*, which describes evening courses, and *Day Courses in London Colleges*. These are very useful and you can get a lot of helpful suggestions from them. The only trouble is that when you ring up the colleges in question, they say, "Oh, we stopped that course five years ago".

The technical colleges come directly under the Ministry of Education which has an Advisory Council for Technological Education, with nine regional advisers. I wrote to each of these listing most of the topics shown in the table and asking if any courses covering these subjects were run. I had letters back from all of them and you can divide the replies into two groups: there were those who took one look at the list and said "No, nothing", and those that read down the list until they got to radiation who said "Yes, we do". However, when I went to see one of the regional advisers I was able to get the *Bulletin of Special Courses in Higher Technology* and it became clear that a number of courses which are very pertinent to the topics listed were in fact run at various places throughout the region. It is a question of slicing the cake a different way. When the regional advisers were faced with my list they did not see what I was trying to get at, at all. When I explained further they were very helpful and eventually divulged useful information about courses.

One other source I tried in this country was the Royal Society of Health which runs a Diploma in Public Health Engineering. This is obviously a comprehensive course, but not in occupational health engineering, although there is a large overlap. The Society does not itself run training programmes but it was able to give me a list of colleges in the area which covered their syllabus. The half of this syllabus covering environment, atmospheric hygiene, ventilation, heating, lighting, radiation, is very pertinent to our subject.

Altogether, if one looks through all these books and prospectuses, one finds that one can cover quite a list of the subjects shown above the line in the table. There are courses on atmospheric pollution and industrial waste, there are quite a number on heat and cold, heating and ventilation and on lighting. Recently, there has become available a short course at Loughborough College on ergonomics. There are several on noise and radiation. I was tempted to feel that it has become a status symbol for institutes of higher learning to run a course on radiation. You pay your money and take your choice. It costs 10s. 6d. at the L.C.C. or £260 at Harwell!

In summary, I would say that, in the United States, there are comprehensive courses, the virtue of which I leave you to discuss. In this country, there is nothing comprehensive, but by diligent searching you can get individual series of lectures on a number of the topics at the top of my table. Those at the bottom are, for someone already working in industry, perhaps less important. There is least available on the subjects listed in the middle.

In commenting on these courses, it is not easy to make any estimate of the standard at which they are run or the criteria for recruitment of students. Some indication, however, is occasionally given, and I would like to finish by reading

you an extract of a letter I received a week after I had written to one college for their prospectus:

"Your future career is a matter of vital importance. I feel sure you would not have written had you been content to jog along in the same old job with the same old fear of stagnation at the same old rate of pay".

Acknowledgement—I am indebted to Wing Commander J. W. G. McDougall of the Royal New Zealand Air Force for help in collecting material for this paper.

A PROPOSED FULL-TIME COURSE

S. A. ROACH

London School of Hygiene and Tropical Medicine

At the London School of Hygiene we are planning a course in Industrial Hygiene Engineering lasting for an academic year. There is apparently an unwillingness on the part of small and, indeed, large organizations to recognize that a man should spend a year learning this particular skill. On the other hand, those who are in close contact with industrial hygiene appreciate the amount of knowledge needed by an industrial hygiene engineer and believe that an extensive and long training is required before he can become competent.

In a large enough company most, if not all the skills that an industrial hygiene engineer possesses, can be found in one department or another. What is lacking is a cohesive and integrated knowledge of industrial hygiene. The industrial hygienist is a focus to which problems of environmental hazards from all sources are directed and from which can stem an organized, well balanced control programme.

An industrial hygiene engineer is someone with a general and broad field of knowledge rather than a specialist in one particular subject. He deals with two kinds of problem. There are those which are sufficiently obvious to others to give rise to open complaints from the workers, or at least concern for their well being, but there are many, sometimes more subtle problems, which he comes across in his routine surveys of the environment. In such surveys the industrial hygiene engineer investigates all kinds of hazards of which others may not be aware.

These two fields of his work are complementary but the second requires a study of the general environment for which a specialist in a particular field is not equipped.

The person who comes to a course of the kind we envisage at the London School of Hygiene will probably have little previous knowledge of industrial hygiene. We hope to take him to the stage where he could be employed as industrial hygiene engineer working for a company. That is, the course is essentially vocational training.

First he will require some background knowledge of industry and occupational health, including the structure of industry and industrial relations. An understanding of certain aspects of the law will be necessary. He also needs to know about the functions of management, trade unions, government inspectors and industrial health services.

The main core of the course will be *industrial hygiene engineering*. This includes the measurement and control of chemical, physical and biological hazards; particularly gases, liquids and dusts. Ionizing radiations and other radiations such as ultra-violet and infra-red will come in as part of the course. Noise, temperature and pressure should, of course, also be included. Atmospheric pollution is another subject, as, indeed, at the other extreme is water pollution. The industrial hygiene engineer needs all these subjects in order to be able to characterize the environment; to be able to describe in so many figures and words the state of the total environment in a particular company.

Apart from this, as we heard from Dr. Hickish this morning, a useful and important part of his work is the recommendation of changes in the environment, which are made to management. Most of these recommendations seem to take the form of suggestions for improving ventilation in one way or another; either general increase in ventilation or local ventilation of machines. Ventilation is the most important tool of the industrial hygiene engineer in controlling the environment.

The duties of an industrial hygiene engineer do not end at making recommendations. When action has been taken he has to repeat his measurements to verify that the steps taken are adequate. The usefulness of an industrial hygiene engineer depends very much on the promptness with which he makes a survey and produces a report.

To understand and to measure the various contaminants in the air, the industrial hygiene engineer uses a number of different instruments. He may, in fact, need facility with some fifty different kinds of instruments. He is working all the time with them and we feel that such a person needs some knowledge of the design and testing of instruments, so that he can understand them properly and make a useful contribution to their improvement.

In order to organize his sampling effectively, the industrial hygiene engineer must have some knowledge of statistics, because there is nothing quite as variable as the environment of an industry. We plan to do this within the general programme, in a course on epidemiology and statistics; the epidemiology in order to understand the way in which the problem presents itself in a population working in a particular environment, and the statistics principally to interpret the environmental measurements correctly.

This set of lectures and practicals will include some account of the purpose and methods of epidemiology used in clinical and environmental studies in the field and the laboratory. Field studies will be emphasized because it is from such work that permissible levels are derived. These permissible levels or MAC's are the yardstick with which the industrial hygiene engineer works. He is seldom concerned directly with their determination but since he uses them, he should have an appreciation of how they are derived so that he can interpret them properly.

The industrial hygiene engineer is not concerned primarily with the acquisition of new information on the human response to environmental hazards but with the application of existing knowledge to ensure these hazards do not arise. In this work close liaison with a medical department is desirable but by no means essential.

The kind of person coming to our course might perhaps have only a very simple idea of physiology and toxicology, and little or no knowledge of industrial diseases, yet, in order to be able to get a feeling for the subject, he must surely know something of the machinery of the body and its reaction to toxic agents. To do this within the general programme we will include a course in physiology, toxicology and industrial diseases, taking special care to instil the elementary principles of physiology so that the student will understand the reaction of the body to adverse environmental conditions. These include temperature, humidity, pressure and noise as well as air contaminants. Toxicology is at the root of the concept of MAC's and the elementary principles of toxicology should be covered. In addition to knowing how toxic materials enter the body and the effects they have, we think the engineer should also know something about accidents and their causes.

This comprehensive programme is very much a vocational training and, as

such, should as far as possible be taught by industrial hygiene engineers. Demonstrations will go hand-in-hand with the lectures. In addition there will be laboratory exercises using the different instruments. These exercises in environmental measurements will be related to his work in the future.

We have heard this morning how the young industrial hygienist needs to get a feeling for industry by practical experience. In sympathy with this view we think it is essential that our course should include visits to factories and other institutions concerned with this field. Moreover, as something more specific and to give real experience in the practical side of industrial hygiene, compulsory attendance for at least two weeks in industry or at a research organization will be required. Preferably a company will be chosen where there is an industrial hygiene service.

This course is in the planning stage. It will begin in October 1961. It will lead we hope, to a diploma in occupational health and hygiene. We would very much like to hear your comments on the kind of things that should be included in it. This is very new in this country and undoubtedly we will at first make many mistakes.

It is the first extensive post-graduate course of its kind in this country; giving education in depth in occupational hygiene.

From these small beginnings we hope that this university will develop a teaching programme in occupational hygiene which attracts graduates of high ability from Europe and the Commonwealth Countries and equips them to measure and control the health hazards of work.

APPENDIX

London School of Hygiene and Tropical Medicine Course in Occupational Hygiene

Duration and fees

The course will be whole-time starting on 2 October 1961 and will last approximately nine months with short vacations of two to three weeks at Christmas and Easter. The fee is £73 10s. 0d., including school registration fee of £3 3s. 0d. (payable in advance).

Qualifications for admission

It is open:

- (a) To graduates whose undergraduate studies or whose previous experience have provided a suitable preliminary training. In general graduates in physics, chemistry, engineering, medicine or allied subjects would have the necessary background for this course.
- (b) In special circumstances to non-graduates with the necessary previous education and experience. Non-graduates must satisfy the school authorities that their previous education and experience qualify them to rank on the same level as graduates.

Training fellowship

The School can offer a training fellowship to enable a suitable graduate to take this course with the prospect of appointment to the staff of the Department of Occupational Health at the London School of Hygiene and Tropical Medicine at the end of this course.

Diploma

The school is asking the University of London to establish an academic Diploma in Occupational Health and Hygiene. If the University is not able to establish such a diploma for this course it is proposed that the School itself should offer a certificate in Occupational Health and Hygiene.

CONTENT OF COURSES

*Systematic instruction.*1. *Background to occupational health*

The structure of industry, industrial relations, the law, the functions of management, trades unions, government inspectors, personnel and industrial health services.

2. *Occupational health engineering*

(a) The measurement and control of chemical, physical and biological hazards of work, including toxic gases, liquids and dusts; ionizing and other radiations; noise and vibration; abnormal temperatures and pressures; atmospheric pollution; industrial wastes.

(b) The measurement and provision of safe and comfortable conditions of work; heating, ventilation and air conditioning; lighting; machine design.

(c) The design and testing of instruments used for environmental measurements.

3. *Epidemiology and statistics*

(a) The purpose and methods of epidemiology used in clinical and environmental studies in the field and laboratory, particular attention being paid to experimental design and sampling techniques.

(b) The determination of permissible levels of exposure to environmental contaminants.

(c) Techniques used for the statistical analysis and presentation of data concerned with environmental measurements.

4. *Physiology, occupational toxicology and disease*

(a) Elementary principles of physiology; reaction of the body to the environmental conditions including temperature, humidity, barometric pressure and noise.

(b) Elementary principles of toxicology; mode of entry of toxic substances into, and their action on, the body.

(c) Description of accidents and occupational diseases including the pneumoconiosis, poisoning by metals, solvents and gases; dermatitis; effects of ionizing radiations.

5. *Information and reports*

Sources of information and use of libraries; the presentation of technical reports and scientific papers.

Practical instruction

(a) Practical demonstrations illustrating subjects dealt with in the systematic instruction.

(b) Exercises in environmental measurements relating to occupational health in the laboratory and in the field.

- (c) Visits to factories and other places and institutions of importance to industrial health.
- (d) Attendance for at least two weeks at an industry or research organization for the purpose of gaining practical instruction in industrial health engineering.
- (e) Keeping a practical note book.

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CURRENT VIEWS ON THE TEACHING OF OCCUPATIONAL HYGIENE AT MANCHESTER

R. E. LANE

Nuffield Professor of Occupational Health, Manchester University

I AM very pleased to hear that Professor Schilling has managed to get the two bright young men, to whom we have just been listening, to carry forward the idea of a whole-time course. This is obviously an experiment we must make in this country.

As one has seen this subject developing over the last two or three years here, I have been struck by the similarity with the situation as it existed in industrial medicine twenty-five to thirty years ago, in this country. In fact, when the Association of Industrial Medical Officers started in the middle nineteen thirties, we were discussing exactly the same sort of problems then as they applied to industrial medicine, as we have been today as applied to occupational hygiene. I thought, therefore, that there might be some value in looking for a moment at what happened about the training of industrial medical officers. After the war, there was an opportunity to go all out and train industrial medical officers, to give them a whole-time course.

We set up three University centres of Industrial Medicine in these islands and two of these gave a course of whole-time instruction lasting an academic year and leading to a Diploma of Occupational Health. We attacked this with great enthusiasm and turned out a number of industrial medical officers, and at the end of the third year, we had nowhere to put them. In fact, this whole business collapsed. We could not carry it forward because there was no one to employ the people we were prepared to train. Therefore, I think it would be quite wrong now if we all did the same thing. I think one centre giving whole-time training is enough at the present time. In my view it would be wiser if we, in another university centre, offered a different type of training.

I should just like to say what we are doing for industrial medical officers in Manchester now. We are giving a training which lasts over two years but is part-time. These doctors spend a day and a half with us, and during the time, they earn their living and they work in industry or they work in general practice. There are twelve of these men, half general practitioners, half industrial medical officers. They come in and spend, in the university, a day and a half a week. They bring their problems and they discuss them, and it seems to me that this is providing a practical and needed method of training industrial medical officers. They bring to this course the experience which they are gaining all the time in their day-to-day work and, I emphasize this, they are earning their living and there is no emotional stress about whether they are going to get the diploma and a job at the end of the course; already they are more or less provided for.

It may be that the time will come when this sort of course will be required for occupational hygienists but they have got to be thicker on the ground than they are at the present time for this sort of course to work.

In the meantime, may I tell you what we are doing for these people and what we have done for some time? First we have financed and trained research fellows. The first of our research fellows is your late scientific secretary, now your secretary. We have had four such people who have come into the department, who have worked on research projects, who have taken our M.Sc., or Ph.D. I am afraid, two of them have gone off to the States; we are so far retaining two in this country and I hope they will continue to stay with us. I feel strongly that there is a need for the training of a few men "in depth" in this country. If a man of the right sort can go into an academic department, say for three years, he can absorb much of the biological approach; he cannot help it. He lives among doctors, he lives among people whose primary interests are biological, and he, at the end of this period, is a person who is capable of leading in this field. It seems to me that if this subject is to prosper, you must attract a few men of the highest quality, and men who are capable of achieving considerable academic background. I would say, therefore, that this is one method, and an important method, of training which university departments such as mine should offer.

What else should we do and what else can we do? In the training of industrial medical officers, we have had great help and found very useful a short refresher course; the sort of course that lasts for a week to which people come from a distance and they live and work together pretty intensively for a week. They get to know each other; they get to know the department; they get a real glimpse of the subject and they learn from each other, as well as from us.

It seems to me that this may be a useful sort of course to run at the present time. I was very interested to hear Dr. Fortuin suggest that this was, perhaps, a reasonable way to start. Obviously, such a course must be open only to people who are practising in this field. They are practising in one particular branch of it. They may feel that they would like to come and swap experiences with others in a similar branch. They may feel that they want to know something about another branch, so we propose to run, in Manchester, starting on 8 May, a week's course in which we hope we shall have about a dozen people already working in this field who will spend this week together with us. They will have the opportunity of meeting people experienced in the various branches of the subject and of discussing problems together.

It seems to me that this, together with the opportunity provided by a Society such as this of swapping experiences, getting to know where the experts hide themselves and how to get at them, is something that may be of value. At any rate, we intend to run such a course. It starts on 8 May, I repeat, and I shall be very pleased to report to you how it goes and whether we really feel that it fills a need.

At present, therefore, this is my suggestion: that we should continue as we have been doing with a few fellowships. These people are few and far between: one every two years or so from a university department. Secondly, that we should offer a short week's course which merely gives people an opportunity of getting to know each other, getting to know something about other branches of their subject, and perhaps, when the demand increases, we might run a part-time course extending over a year or even more, rather on the lines we do at present for industrial medical officers.

CURRENT VIEWS ON THE TEACHING OF OCCUPATIONAL HYGIENE AT THE UNIVERSITY OF DURHAM

R. C. BROWNE

Nuffield Professor of Industrial Health

FIRST of all, a word of thanks for asking me to be your guest and give this paper. The plight of the last speaker on a day like this is pitiable indeed, because he could do one of two things: he could do the President out of a job by summing up, inadvertently or advertently; he could merely dot the i's and cross the t's, or merely say what has been already said again. This will happen to a certain extent, but I suggest that the points which are made on which there has been general agreement are the important points which have come out of today's discussion.

The first question I would like to ask is, how many occupational hygienists do we need to train? I hope sincerely that those we need in this country we will train in this country. Next, whom should we train, where should we train them and how should we train them?

How many? Wait for the demand would be the wise thing to do. My own feeling is that we are probably not quite at the point to train many yet, and I do underline Professor Lane's point about training people for whom there are not jobs. We should probably train in single numbers, thinking about the larger industries and what future industrial health services mature, or survive might be the word, over the next five or ten years.

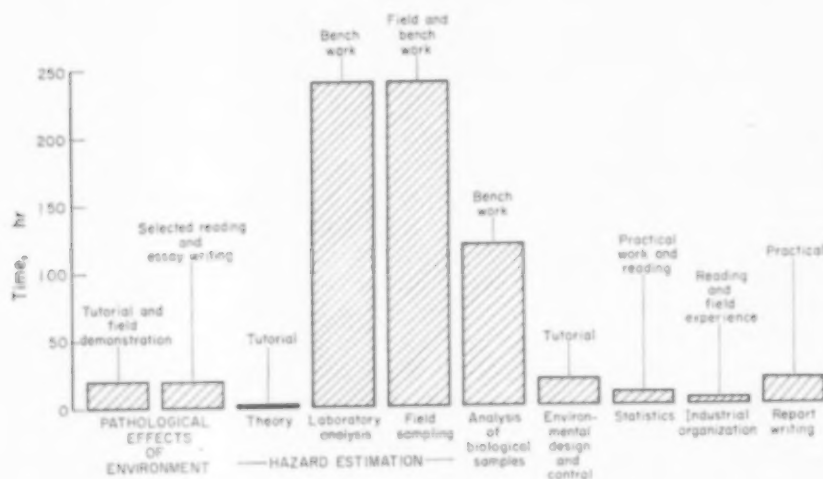
Whom should we train? It is not possible for all of us to know everything, whatever field we are in, and we have to make the best compromise. For the generality of industry with a lot of mixed problems, and in a large number of small units the chemist is perhaps the man, followed in order by the physicist, the engineer and the doctor. I say doctor on purpose, not necessarily for British or United Kingdom consumption, but I can conceive of Commonwealth industrial organizations, in fact I have visited some of them, where a doctor might have to be his own occupational hygienist. There are, of course, special types of industry: the ionizing radiation industry or the National Coal Board, in which the occupational hygiene problem is very largely a physical one, and for these special places, the physicist is your man.

If you advertise for any of these people to come and be trained for an occupational hygienist's job, you will not get much of a response. All these people are worth their weight in gold. They are in very short supply indeed. You cannot even fill university appointments at the moment, with engineers. We can only just fill them with chemists and physicists and are running short of medical men.

The figure shows a suggested Newcastle course for training occupational hygienists. I may say that when we constructed this, "we did our homework entirely unaided" as the phrase on the children's school report goes, but it is extraordinarily like Professor Schilling's course. There are however one or two little points of

different emphasis. We have attempted to estimate the hours of instruction, for administrative reasons.

It is most important to keep all this instruction on as personal a level as possible, using tutorials, field demonstrations, and very clearly discussed reading and essays as the main tools. The smaller the number of people, the better will be the quality of the course.



I would draw your attention to the two columns going up to nearly 250 hours. This makes the point that this is essentially a practical course with considerable time given to field and bench work, sampling, and estimations. Instruction is needed in estimating with some tutorial work on biostatistics. I would not put in quite as much as in the suggested London course but would let it rather go along with the other subjects using the statistics when they have to be used. Industrial organization: this merely says what has been said already. It is most important that when an occupational hygienist goes into a factory, he knows what the managing director, departmental managers, welfare officers, and all these various functionaries, do. He should also be brought to realize that the organization of industries differs as between industry and industry.

It is most important that he receive instruction in report writing; that the reports be clear. They should not go into too much technical discussion and they should be delivered as rapidly as possible after the inquiry has been made. Speed is a selling point in this field.

There is not room for more than one course in the country. Would it be worth suggesting that it should be a joint course between London and Newcastle?

DISCUSSION ON THE AFTERNOON SESSION

DR. GILSON said that among the questions he had posed in his opening remarks was, who would pay for this training. Not much had been said on this point. The D.S.I.R. provided bursaries for training in radiological health. Could not they also provide these in the wider field of occupational hygiene?

PROF. SCHILLING said that he had got what might be called a bursary to train one person for a year in the whole-time course with the prospect of their becoming a member of the department at the end of the course. The Ministry of Labour had also been approached to ask them whether they would be able to offer bursaries to people who were going to take the whole-time course in the same way as they gave extremely valuable help to nurses who took the Diploma for Industrial Nursing at the Royal College of Nursing. He did not know what the answer was, but certainly the response of the Ministry of Labour had not been unsympathetic. In other words, they were considering it and wanted to see the sort of people who were going to respond to the advertisement for the course.

MR. P. C. G. ISAAC underlined a point on the training course. For the last 11 years, he had been running a post-graduate course in public health engineering which was somewhat analogous. It was now 4 or 5 years since he had any Briton in the course at all. They were usually about one dozen students a year, entirely supported by the World Health Organization, by overseas governments or by their own travelling funds for the miscellaneous treaty organizations throughout the world. The Treasury could not, however, be persuaded to support Britons.

DR. DIXON (Esso Petroleum, Milford Haven) said that the afternoon's discussion centred on two things: who was to be trained and what they should be taught. As to who was to be trained, engineers had been talked about, chemists had been talked about, physicists had been talked about and even doctors. He was amazed that, throughout the discussion and throughout the description of the courses, so little attention had been paid to industrial injuries as opposed to industrial diseases. It had to be remembered that 600 to 700 people had died the year before as a result of industrial accidents. He felt that this was an important aspect of industrial medicine which tended to be neglected.

Anyone who had worked on a large construction project, as he had, would realize only too well the importance of that aspect of industrial medicine.

He could see that many people felt that a very small number, in some cases, of fully trained industrial hygienists were required in this country, but there was an impression that a large number of people were required to do simple measurements, to advise the industrial medical officer, or assist him in doing measurements in his own factory. There was a large number of medical departments in this country which took the same enlightened view as his own, that the safety department should go under the medical officer. He fully supported that view. He felt that the safety engineer, who was usually a man with A.M.I.Mech.E., or a similar educational background, was a very suitable person to train in the simpler industrial hygiene methods. The suggestion was put forward that universities should be encouraged to design relatively short courses, a week or two, which would appeal to management

to send safety engineers to, and a valuable reservoir might be produced of personnel which could carry out that sort of work. The problem of payment then ceased to be of such seriousness because most managements would be quite willing to send their safety engineers on such courses. The courses on radiation were already over-filled.

He suggested that the safety engineer should be considered as a more suitable person for training in industrial hygiene.

DR. J. M. ROGAN (National Coal Board) said that he had no doubt at all that if good courses were run of one month's duration for hygienists in general, industry would pay. They would not pay for a man to be absent from work for nine months, or six months, but if it came down to one month, he thought the response would be considerable, provided the instruction was good.

The Chairman commented that a firm would pay for 26 weeks on a medical certificate.

DR. J. G. FORTUIN (Messrs. Phillips, Netherlands) suggested that the four weeks should be divided into two periods of two weeks, so that, between the two periods, a man could arrange his own business and keep his department going.

A previous speaker had said something about people who could do simple measurements. He wished to give a warning. He had started in the field some 10 years ago with simple measurements. Now he was aware that he was in no simple situation.

MR. ADAM (United Steel Companies, Rotherham) said that he was very much interested in the course as a prospective customer, but the feelings of his company were that they definitely would not let him go for nine months. They thought that three months at any one time was probably the maximum. They could also stand three two-month periods in consecutive years rather than a whole six months at once. From what he had seen of the course, as a graduate chemist, he would find the analysis of the samples very easy. Taking the samples and making them as representative of what one wanted to measure was a much more difficult gambit from the chemist's point of view. Leaving out most of the proposed course, as far as bench analysis was concerned and concentrating on training, or making a good representative survey in the field, would more or less cover what was needed, apart from remedying the bad conditions when they come across them.

He would like any course he attended to concentrate very largely on the engineering aspects of industrial hygiene. He thought that the people who were going to send representatives to the course would have statisticians and medical officers in excess of industrial hygienists. He could go to his medical officer and he would arrange for as many talks as were wanted on physiology and those aspects of the job. To him, that presented no problem. He would just like to see the course concentrated on engineering.

DR. PETERS (War Office) said that it seemed to her that this should be dealt with by building upon existing organizations. In a way, this was a pioneer thing, but some work had been going on for years. On the other hand, it was new, and therefore it would be regarded with suspicion, both in regard to expense and whether it was going to add to the cost of production. Those were objections one met in industry. If the new idea could be cloaked under an old name, everyone was quite happy.

Another point was the numbers involved. Who was it going to attract? Dr. Dixon's suggestion, that safety officers were the people, was excellent for meeting those two points. She did not say that it was ideal. One had to work through

stages. There were safety officers; most people knew they had to have them. They were frequently engineers and it seemed to her that of all people, the engineers were the people who had to learn. She had never so far met one doctor who was an engineer, and the engineers, after all, had now to cope with toxic hazards.

Fundamentally, she thought that engineers had a very heavy weight on their shoulders and she blamed engineers largely for most of their troubles because they had not designed plant to cover the *desiderata* shown on the blackboard. Until engineers re-designed plant on that conception, they were sunk. Everything that was done now was merely a stop-gap. It seemed that engineers were the people to get at. She suggested that their heel of Achilles was safety officers who were readily accepted and would be to hand. She suggested that safety officers be plugged. One had to do things in stages. One had to be careful. One could not go against public opinion or be in advance of public opinion. They had to work from small beginnings. Therefore, she would plug for the safety officer to be the person. He was the fish they should try to hook.

MR. W. P. KENNEDY (Distillers Company) supported Drs. Dixon and Peters and drew attention to what might be called the logistics of the problem. One had to consider the number of people involved and the amount of overhead which could be allocated to the particular factory. He had in mind a problem his company had with a factory of just under 400 people, when they needed a hygiene officer for the problem they had there. It was a food factory. At about the same time, the necessity also arose of appointing a safety officer, full time; for a factory of 400 people, which had not got a very marked hazard, a full-time safety officer was an expensive item. Previously they had had only a part-time man. The problem was solved by getting one officer, first-class ex-R.A.M.C., who had been involved in teaching hygiene in the R.A.M.C., as their hygiene officer and giving him a safety course of some six to eight weeks' training. He was put on the job, so he was part-time safety officer and part-time hygienist, working with a part-time medical officer. He instanced that, without discussing it in any great detail, as a solution, and it had proved an extremely good one. The man was very efficient. It was a solution to the problem of the intermediate-sized factory, and it was one which also applied, of course, to a very large number of factories in this country. It was a very different thing from one firm employing 2000 or more employees. He supported what Dr. Dixon had said about joining up the functions of the safety officer with those of the industrial hygienist, especially in factories of a medium size.

The Chairman said that traditionally, R.A.M.C. hygiene did not quite cover the same field. He asked if there was anyone from the Army School of Health present.

COLONEL D'ARCY (Director, Army School of Health) said that hygiene in the R.A.M.C. with regard to hygiene assistants, covered a wide field and they were concerned with industrial hazards associated with W.D. workshops. Certain of the subjects mentioned were covered in their training; for example, emphasis was now placed on peace-time uses of ionizing radiations. In general, they did not go into the detail of occupational hazards required of the occupational hygienist.

DR. D. E. HICKISH (Industrial Hygiene Engineer, Slough Industrial Health Service) said that Professor Browne had mentioned the difficulty of getting engineers, chemists and physicists to go into the field, yet it had been his experience that when a chemist had been appointed to do analytical work, that chemist had been fired

with great interest in the field of occupational health and immediately wanted to branch out into the general field of occupational hygiene rather than chemistry.

He could think of no one who had gone into the field of occupational hygiene and gone back to his original occupation; it was a fascinating subject.

Professor Lane had mentioned the possibility of training research fellows from time to time. He himself wondered whether one of the sources of candidates for that training was not going to be from undergraduates who had had some indication of the potentialities of the field of occupational hygiene. It should be stressed that the subject of health had never been mentioned to the average engineering undergraduate; if it was, there might be more candidates.

He pointed out that an A.M.I.Mech.E. was a chartered professional engineer and was capable of more than simple jobs.

DR. CHALLEN asked Professor Schilling the minimum number of students he required for his course.

PROF. SCHILLING said they ought to have six to run a course. It was never economical, but to make it worthwhile, six would suffice.

DR. CHALLEN said that it was extraordinary if, in this country, the large industries and trade associations could not find six bursaries for students for this course.

DR. G. JONES (Richard Thomas and Baldwins) asked what the actual cost would be to an individual firm of sending one person already on their staff to Professor Schilling's course? Would an estimate of £1200 be a realistic one, in return for which, a trained occupational hygienist would be returned to them?

THE CHAIRMAN asked if loss of the man's services for nine months was being taken into account.

DR. JONES replied, three-quarters of his salary, the cost of the course and some help towards the cost of his lodging in London. A new appointment was, of course, being made; when he returned, he ceased to be one of the firm's chemists or physicists but he would be its occupational hygienist, and that could be obtained for £1,200, which might or might not be economic. He did not know.

THE CHAIRMAN said that in such a position, some firms required a man to give two years' service after rejoining, which seemed quite reasonable.

MR. B. H. HARVEY (Factory Inspectorate) confessed to some slight apprehension after Dr. Wood's talk because he felt that a large number of technical colleges had been triggered off by the enquiries of Dr. Wood who asked searching questions as to whether they had a course along the lines detailed. He might one day open a newspaper and find courses advertised inviting him to become an industrial hygienist by correspondence.

He thought that an important factor in deciding how to train engineers was to try and think what the end product would be; what the occupational hygienist would be. It was important to say "This is the sort of man we want". He was rather disturbed by the list of proposed subjects in the course, which put industrial experience and background last. The most important thing about a factory were what was made there, what the end product was and what it was made from. It seemed to him that a fairly wide industrial experience was necessary before the industrial hygienist was going to appreciate small hazards from large ones, and when he had got a real problem and when he had not got a real problem.

Some experience factor had to be built into the industrial hygienist. The word "engineer" today did not allow an engineer to become a corporate member of the

institution until he was, in the case of the Mechanicals, aged 26; by 26 he was considered to be reasonably safe and to have had enough experience to call himself a chartered mechanical engineer. That was where an engineer could build into his profession the experience factor. He wondered whether the Society, or some similar organization, should take a step in that direction? Obviously, industrial hygienists trained in one school would be different from those trained in another school, but if the engineer was a chartered mechanical engineer, one knew what he was and what experience he had had as an engineer.

PROF. SCHILLING thought that some questions ought to be answered, and the reasons which lay behind the suggestion of a nine months' course given.

In his department, in discussion with other people, it was felt that to be an occupational hygienist, the sort of person capable of doing the things described, needed a pretty skilled person. It was felt that if the subject was going to develop and thrive in this country, there had got to be some people who were really skilled in the job and not merely technicians. That was one of the main reasons why a nine months' course was suggested, so that a small cadre of people would be trained who would be really skilled in the job. Those would be people who might go into large industries.

He found it difficult to believe that large industries could not afford to send a man to train at the London School of Hygiene for nine months when some of them could afford to send a man to the United States for nine months. One would hope also that, sooner or later, there were going to be, in this country, occupational hygiene services in regions, and the people who were going to direct and develop those services had got to be skilled people who had had nine months' training in occupational hygiene. There was a case for the person who was going to do research work in a university or at one of the Medical Research Council units to have done a nine months' course. He thought that it was worth trying. It did not look as if they were going to get much in the way of response this year but he felt they should start really high in an attempt to put the subject on the level it deserved. It was very much more than being a technician and going round measuring things.

DR. WILSON (Stanton Ironworks) said that, in his opinion, it was far too all-embracing for any one person. In his organization, machine design was a function of the production engineering department, and that in turn depended on the drawing office, so they would want a draughtsman to go for the machine design part of the course. Atmospheric Pollution was under the estates manager, industrial waste was in a certain section of the research department, gases and dust went under another section of the research department, heating and ventilating went under the drawing office, which was the design engineer's job. There were numerous different jobs all in the same course.

He would like to see the course split up into monthly sessions so that a man could go to one or more sessions, according to his inclinations.

DR. J. R. GLOVER (Westinghouse Brake and Signal Co. Ltd.) said they must face the problem that they were starting a new post-graduate profession: could they not learn from the experience gained in the formation of the other professions?

The Medical started as apothecaries and became doctors. After that, they embraced Industrial Medical Officers. Nurses started off as "Sara Gamps" (he was not sure if there was another word for them before they were qualified), became State Registered Nurses, and then became Occupational Health Nurses. At each point a

new profession was formed and the following things were required: a journal; a title; respect; a degree or a diploma following examinations, and a society.

What had we got to do in this society? We had got the society, and the journal. One of the things lacking was a proper title and that was one of the big stumbling-blocks; it was a very important psychological block at the present time in industry. There were no examinations, nor degrees; there was little respect because no one knew what to respect. In each firm or organization the industrial hygiene problem was sometimes referred to the doctors, sometimes to the chemist, or sometimes to an outside specialized unit. Therefore it was very difficult to give respect to a profession which had not got a quickly recognized title or an obvious function.

How had the previous ones got over that block? Apothecaries already practising were allowed to continue and the new entrants by law had to become doctors. They themselves did not need that: they were not so important, at the present stage at any rate, to make it a law that people could not practise industrial hygiene without being qualified. Very soon, the old unqualified apothecary dropped away and the new profession was complete.

What of the Sara Gamps? Those present in the room were the Sara Gamps of Industrial Hygiene; in other words members of this Society, the doctors, physicists, chemists and occupational health engineers. (The latter title, he thought, was the best, as far as he was concerned in his dealings with industrialists, this was a purely personal opinion, though not an original one.)

What must they do to encourage firms to press their own personnel to become qualified? First of all, the group of doctors was going to stay doctors, even if they went through the barrier; therefore, the majority of them were not going to be trained and take degrees, as professional industrial hygienists, though many might like to take a diploma on industrial hygiene, as quite a bit of their work was taken up with occupational health engineering.

Several chemical industries, and oil companies had the industrial hygienist under the doctor, and, in general terms, the more industrial hygiene hazards there were, the more likely it was that the industrial hygienist would come under the doctor. If the doctor was going to be in charge, what parts of industrial hygiene did he know already and what did he want more? He wanted measurement and advice. He did not want interpretation of results. Those who had worked for some time on those problems had to do the interpretation not from industrial *hygiene* literature but from industrial *medical* literature, which only medical men are capable of assessing in a works.

The measurement was divided into dust, chemical and physical (noise and lighting).

What basic training was required for an industrial hygienist? It should not be forgotten that the doctor had already studied inorganic chemistry and a considerable amount of organic chemistry which, though he would not necessarily remember it, he could soon revise. He was one of the few men in a works who could talk chemistry. Dr. Glover suggested that heating, ventilation and comfort had been necessarily left out of the medical curriculum, and that heating and ventilation engineers would probably supply those techniques which the Industrial Medical Officer lacked. As they had heard this morning, from the most successful heating and ventilation engineer in industrial hygiene, most of those problems ended up with advice on heating and ventilation.

Therefore, his four main points were:

1. That heating and ventilation engineers should be strongly considered as candidates for the projected course.
2. That we must create the demand (the need exists, the demand does not) for our new profession by agreeing on an acceptable title.
3. That we must encourage all those who are already practising occupational health engineering in industry, whatever their basic graduate discipline to enter the examinations and gain the diploma, and with this in mind:
4. That a nine months' course was too long.

As there did not appear to be an owner of a small factory present, he would say a word about them. He started by giving the example of a small factory in his area which was criticized by a Medical Inspector of Factories for bad ventilation. The Factory Inspector returned some months later and the man said with pride "Look what I have put in", and shewed him an ozonifier at a cost of £1500. The Factory Inspector had to tell him that ozone was a poisonous gas and he must remove it!

This seems to epitomize the problem of the owner of a small factory, namely that when one is struggling to break into the commercial world one is working to a very small budget, and if there is money to spare for such things as ventilation or better washing facilities, then the small man has no specialized industrial hygiene knowledge to know the best and cheapest way of putting in the correct equipment. For example, in many cases if the Factory Inspector pushed hard enough and made these small factories put in accurate and good factory ventilation they simply could not afford it and would become bankrupt. Nowadays it would cost the manager of a small Fettleing Shop of 20 men as much as £15,000 to put in the right equipment.

The man who starts up a business on his own is to be admired, for as soon as he starts operating he has to fulfil the following functions: managing director, personnel manager, foreman, salesmanager, export manager, safety officer, supervisor of first aid, financial director, cost accountant, and last but not least an industrial hygienist. He is at once harassed by the Income Tax Inspector, Factory Inspector, and Public Health Inspector, and how with a limited capital expenditure of say £100-200 a year can he be expected to pay for an Industrial Hygiene Service on a fee paying basis, when he has barely enough money to pay for the equipment they would advise him to install afterwards.

To his mind there was only one way, there must be a free Industrial Hygiene Service, and the small business man must be "sold" industrial hygiene in the sense that he would save money by employing the service because he would get the right advice to buy the right equipment at the right price, and not put in for example a useless ozonifier.

It might be asked why has this problem of the small man been brought up during the session on training. It is a re-emphasis of Dr. Dixon's point that the climate in industry towards industrial hygiene must be changed by winning over the larger business concerns, Government Departments, and Members of Parliament, and he would agree that one of the best methods of doing this would be by using Television and the Press. For without a change in attitude there will be no posts in industry to train people for, nor even a small well-trained country-wide cadre around which one could form an efficient Industrial Hygiene Service.

MR. MACDONALD (Ford Motor Works, Dagenham) said that his line of thought

was the opposite from what other people had said. Professor Lane had mentioned the beginning of industrial medicine and rightly compared the beginning of industrial medical officers and industrial medicine in factories with what was happening at present with occupational hygiene engineers. He wished to pursue that, in thinking on the lines of Dr. Glover, who had talked about the logistics of the problem.

Surely it was not that people talked about running full-time courses for industrial medical officers any more than it was true to say, whatever people might think was right or wrong, that every doctor who now went into industry started off by taking his D.I.H. and then looked for a job. That was, in fact, not on balance what was happening at all. Some people started in general practice and were fascinated by industrial medicine, left their general practice and went full time into it. Some people took training first and went into it full time. Others might get involved in some form, whether it was physiology or some other form of medicine, and go into industrial medicine in that way.

He felt that industry as it was at that moment organized—not as they thought it ought to be or as they would like it to be—had a lot of people in it who were already quite interested in the subject. He thought a lot of people were interested in it now and a great many people were going to be interested in it in three years' time. He did not think that there was any lack of large firms who had got money that they were willing to spend on it, but the hard-headed business man and the hard-headed industrial medical officers, wanted to be a little more certain where they were going, and with whom, before they spent large amounts of money.

There was a considerable point to be made, again thinking of the logistics of it, on young engineers and young chemists who were already on the ladder, not perhaps very high on it, in their laboratories or in their engineering departments. They were not necessarily convinced at the moment that they wanted to go full time into occupational hygiene because they would be the first people to say that they did not know enough about it. He thought that if such people went on the kind of short course that some of those present would like to see organized, they would be increasingly fascinated by it and would later want a course. Those doctors who originally went into industry might well, and with profit, have done a D.I.H. later because of the need they saw for the training.

He did not think it was a question purely of whether a company would be willing to release a man for nine months, although he believed Dr. Rogan was completely right; the number of industries that would like to release a man for nine months must be very few. Industry would be quite prepared—and he knew his company would be quite prepared—to release not one but possibly three or four people for a space of two or three months, and, at a later time, one of those people might even be further released for a long course, but to release a person whose future in the field might be uncertain was different. There were people present who had taken the plunge and had survived and they were the leading people in their profession.

His point was that before one could run one should walk, at least walk fast and not start off as an Olympic hurdler without training.

The argument about long and short courses was not just a question of money, and it was not a question of releasing someone for a long time. It was that they wanted to find the people in the field; they were already in industry and they would profit immensely by a short course. In so far as there was a great deal of industry

round London, if the short course could be arranged in or near London or in the Southern Counties, it would be easier than sending people from southern industries to Manchester or Newcastle, which created difficulties in that people had families and wanted to see them and preferably to go on living with them.

He felt that the matter of a shorter course was one which merited serious thought from the point of view of the future of the profession, including the people at present at the top of it who would want people to join them there later.

DR. J. G. FORTUIN (Messrs. Phillips, Netherlands) said that in his opinion, there was a little difficulty: starting from the drawing of Dr. Glover, which put the doctor in the centre, that was quite right. Then Dr. Glover asked for measurements and advice for the doctor. A lot of speakers asked for measurement and technical advice for improvements from the same person. In his own experience, it was better to have the measurements made by some people who might be called industrial hygienists, and to have the technical advice as to the improvement from some other people. There were people on his Technical Hygiene Committee who were heating and ventilating engineers, but he would not trust them with chemical measurements.

DR. CAMERON (Pilkington Brothers Ltd., St. Helens) said he thought the matter could be divided into two. While he agreed very much with what Professor Schilling had to say about the long course and the need for it, in his own industry, they were in the same situation as Dr. Adam.

Three years before, they had started off one of their own research graduates as an occupational hygienist. They would very much like him to undertake further training, but he was at the point where he was beginning to get established. He had come up the hard way by visiting various people and had got know-how into the particular problem he needed to deal with every day. Professor Lane's suggestion of the short course was the only thing the industry would be prepared to release him for.

As an industrial medical officer, he would hesitate to send him away for nine months because he would hate to see the teething troubles which had occurred at the start reproduced when he came back in a year's time, even though he was very highly qualified.

He hoped that the situation would never arrive where industry got the occupational hygienist before they got a doctor.

R. J. SHERWOOD (Health Physics Division, A.E.R.E., Harwell, written contribution). All industrial hygienists will wish success for the proposed full-time course at the London School of Hygiene and Tropical Medicine, which is the outcome of a steady development of interest in occupational hygiene at the school—stemming from many years' work in the Department of Applied Physiology and the subsequent formation of an Occupation Hygiene Unit in 1960. The latter, which was associated with the Slough Industrial Health Service provided an advisory service to industry in addition to teaching, and was founded on the premise that a continuous programme of field work, supported by research and development, is an essential basis for a successful teaching programme. I still believe this to be essential, to ensure that teaching keeps abreast of current technical developments, and to provide the field work which students need to absorb the practical philosophy of the subject, and to learn the art of establishing suitable relations with management and labour.

We must hope that industry will recognize the opportunities offered and that adequate numbers of students will be forthcoming for a full year's course; those

who have enjoyed the fortune of a post-graduate course in the U.S.A. will fully appreciate that the basic philosophy can most readily be acquired from a long-term course.

However, concentration on a full course should not preclude organization of programmes of short courses which I believe would serve a more immediately useful role. These could take three forms. One would be intended for factory managers and medical officers, and would deal predominantly with non-technical subjects. Its purpose would be to spread knowledge of the value of occupational hygiene and prime the pump for longer courses. The second type of course, lightly leavened with technology, would be aimed at disseminating knowledge among peripheral groups, such as public health engineers and members of inspectorates. It should be put on record that for more than ten years the post-graduate public health engineering course run jointly by Imperial College and the London School of Hygiene has included about twelve hours of lectures on occupational hygiene subjects. These have included measurement and control of lighting, noise and vibration, thermal conditions, and toxic and radioactive substances.

The third form of course should deal comprehensively with some aspect of occupational hygiene, for example the analysis of air and excreta for lead or benzene, or dust counting and micro-analysis. This type of course would be largely concerned with techniques and would be intended for technologists interested in these specific problems.

I believe that at present industry is likely to be more interested in the short-term training of staff to deal with their specific problems than in the production of widely trained occupational hygienists. There are probably few organizations that can make use of a full-time occupational hygienist, but there are equally few industries which would not benefit by the training of staff employed in research and development departments, and their part-time employment on specific problems as occupational hygienists.

I believe that the Society should not only support long term courses, but in conjunction with teaching institutions and trade associations should sponsor courses, lasting a few days, of the type outlined here.

SUMMING UP OF THE CONFERENCE

L. G. NORMAN

President of the British Occupational Hygiene Society

THE Chairman said that they were all abundantly grateful to Dr. Turner and Dr. Steel who were the principal organizers of the conference.

The question of nine, six, three months or one month for the length of the course was a very important one, and was more one of principle than of the length of time for which an individual company could release a man. The principle was that if the subject was to develop adequately, it must have a few first-class people, and one did not get them by providing a month's refresher course, or a month's training in some branch in which they were weak. One did not even get them in a full academic year, but that was aiming higher. If a man already had a graduate training in a scientific subject and then attended a full nine months' academic course, he would have a good foundation.

The principle went beyond an individual company; it went with the whole meaning and value of the subject. To be good, it had to have a few exponents of top quality. There were a few, who had had to go to Harvard. Now a start was to be made in this country. Was there not a place for both long and short courses? There must be a place for the one- or two-month course. Dr. Fortuin had suggested holding a symposium, of discussions with some teaching in a particular section of the subject, lasting two or four weeks. That was a good idea for a brief course.

When Dr. Gilson spoke he had asked "Who pays?" Part of the answer had been given to that. What worried Dr. Norman was that even if the course could be paid for, and occupational hygienists trained adequately, who was going to pay for carrying out the recommendations of the occupational hygiene service, for example, for expensive ventilation improvement in a small and not too successful factory? It seemed difficult to make that expenditure a charge on the State. That, to his mind, was where a major difficulty came in.

Everyone had agreed that the term "occupational hygienist" was not a good one. An alternative suggestion was Dr. Glover's "occupational health engineer", which had been used before. He suggested that Members should write to the Secretary with their suggestion of what the title might be.

Mr. Spencer's opening discussion was magnificent. His sentence "No civilized industrialist would object to the principle of improving environmental working conditions and comfort by means of occupational hygiene" was thoroughly sound. He had struck a warning note about the possible non-availability in future of enough capital to provide the best working conditions, but he had ended on a real note of enthusiasm.

Dr. Rogan had pointed out that there was no formal training in occupational hygiene for scientists and engineers in his own organization. Occupational hygienists were not employed as they would have to be very specialized and therefore have a poor career prospect.

The importance of an adequate career prospect had been mentioned by several speakers. As had been pointed out, one did not start off neatly by the institution of a diploma, training people for it and then pushing them into jobs. Professor Lane's parallel with industrial medicine was close; it grew. Occupational hygiene (or should it be "occupational health engineering"?) had to grow in the same way. It would grow gradually, with a long course for specialists, short courses for others and with people just getting jobs somehow; but the one over-riding thing that mattered was that the standard had to be the highest practicable one. Possibly, the Society could take part in ensuring this.

Dr. Whitehead saw little need for the occupational hygienist in his industry. Dr. Swan was from a large oil company which employed an occupational hygienist; he had found the experience of inestimable value over the past two years. This was typical of what had happened before in the development of industrial medical services.

Miss Crundwell said that the problem from the Ministry of Labour's point of view was to convince industry generally of the need and she had used a rather telling phrase, that the industrialists might fear they were being required to provide the evidence on which to hang themselves. She therefore thought that they should not expect a rapid development in occupational hygiene services. If they could be certain of one thing, they could be certain of that.

Perhaps it was just as well. The subject would grow and it would grow slowly and it was up to them to see that it grew well. There was an encouraging note by Miss Crundwell that there had been an increase in the number of firms carrying out atmospheric testing. With the republication of the American MAC recommendations, slow progress was beginning to be made.

Dr. Hickish, as a practising occupational hygienist, gave some examples of the need, and the Chairman had been struck by the three tasks of the occupational hygienist formulated by Dr. Hickish: recognition, evaluation and advice on methods of control. These were very close to Dr. Fortuin's five points.

One of the most important things that had to be done was to try to bring together people working in the occupational health field; there was plenty of opportunity for separation and segregation, which would delay progress. It was important that they should learn to live together. The word "symbiosis" had been used, which seemed to summarize the position neatly.

The last contribution by Dr. Glover, was an analysis of the logistics of the situation, and he found it convincing. He would like to think about it at some length. It was interesting and very well done.

Dr. Norman thanked the contributors for an interesting day and said that everyone was particularly grateful to the speakers, who had made the Conference so successful.

THE NEW INTERNATIONAL CLASSIFICATION OF RADIOGRAPHS OF THE PNEUMOCONIOSES

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Abstract—The evolution of the various classifications of radiographs of the pneumoconioses is reviewed.

Details are given of the following classifications: the Johannesburg (1930), the American (1938), ECK and HANAUT's (1944), the Hasselt (1948), the P.R.U. (1949), the Sydney (1950), the Cardiff-Douai (1951), and the Geneva (1958).

The new Geneva international classification is given in full; the difficulties encountered in choosing and copying standard films to illustrate the classification are described.

Details of the appropriate X-ray technique for the taking of chest radiographs are given and the use of radiophotography in industrial medicine is discussed.

THE SUBJECT of classification of the diverse radiographic pictures seen in men employed in dusty industries has interested us for a number of years, and special circumstances have recently allowed us to study it more closely. In 1958 we were appointed consultants to the International Labour Office to obtain the opinions of experts throughout the world on the usefulness of the international classification adopted in Sydney in 1950 and to study the trends of opinion in this and related subjects. We were able to gather the views, by personal interviews with many British and European experts, and by questionnaires from those in more remote countries. Altogether, we collected the opinions of 120 experts in sixteen countries in all five continents. Our report to the I.L.O. constituted a large volume, which was used as the basis for a working paper for the international conference on the subject, held in Geneva from the 27th October to 7th November, 1958, under the presidency of Professor Gernez-Rieux.

EVOLUTION OF IDEAS ON CLASSIFICATION

It will not be possible, within the limits of this article, to survey all the varied opinions which we obtained, but it will be useful to consider the basic concepts which emerged from our enquiry. From the first South African classification drawn up in 1916 and an American one in 1917 up to the present time, many classifications have been put forward and to mention them all would take up too much space. We shall try, therefore, to show the evolution of ideas on the subject by discussing the previous international classifications drawn up under the aegis of the I.L.O.: at Johannesburg in 1930, at Sydney in 1950, as well as the latest one at Geneva in 1958, with reference, as necessary, to some of the others. At an international conference on silicosis in Geneva held in 1938, the subject was discussed, but no classification was adopted.

Basically, the abnormal X-ray shadows found in the pneumoconioses constitute

various combinations of linear, reticular, nodular and massive shadows, and none of them is specific in the sense that similar shadows may not be found in other non-industrial pulmonary conditions.

The Johannesburg classification (1930)

The classification of Johannesburg (1930) divides the pneumoconioses into three stages which take into account the clinical symptoms, the capacity for work and the radiographic appearance of the pulmonary fields. Here is the text as reported by GARDNER, *et al.* (1930) in the *Report of the International Conference on Silicosis*, Johannesburg, 1930.

"In the 'first stage', symptoms referable to the respiratory system may be either slight or even absent. Capacity for work may be slightly impaired. There may be a departure from the normal in percussion and auscultatory signs, and the radiograph must show an increased density of linear shadows, and the presence of discrete shadows, indicative of nodulation.

In the 'second stage', there is an increase of the physical signs observable in the 'first stage', and the radiograph shows an increase in the number and size of the discrete shadows indicative of nodulation with a tendency to their confluence. There must be some degree of definite impairment of the working capacity.

In the 'third stage', all the above conditions are grossly accentuated and indications of areas of massive fibrosis are usual. There is serious or total incapacitation."

This three-stage classification or modifications of it, is still widely used at the present time in Germany, the U.S.A., Sweden, the U.S.S.R., and Switzerland. It has been criticized because the radiographic criteria are not precise, but it has been found useful for compensation purposes, because the X-ray appearances are combined with clinical findings. In subsequent classifications the X-ray appearances are put into categories without reference to symptoms or disability, which may or may not be a disadvantage. It is certain, however, that the three-stage classification of Johannesburg of 1930 has been found useful and that it, or its modifications, are still widely used. The experts at Johannesburg in 1930 were well aware of the deficiencies of radiological technique at that time, and they recommended, amongst other things, that action should be taken to establish, if possible, an internationally comparable technique of radiography, and terminology of radiographic findings.

In 1934, Irvine of South Africa (who had been present at the Johannesburg conference) put forward a classification to the Correspondence Committee for Industrial Hygiene of the I.L.O. Here, according to BALGAIRIES, are the 10 rubrics which he envisaged.

1. Normal thorax.
2. Slight accentuation of normal linear shadows.
3. Moderate accentuation of normal linear shadows.
4. Generalized accentuation of the shadows of vascular arborization.
5. Generalized accentuation of the shadows of vascular arborization together with a limited number of small nodular shadows.
6. General distribution of nodular shadows—sparse, agglomerate, small, medium, large.

7. *Idem*, with accentuation of hilar shadows—enlarged hilar glands, apparently calcified.
 - peribronchial thickening.
 - cardiac shadow of special type.
 - nodular shadows of irregular size and distribution.
8. *Idem*, with diffuse opacities; slight, fairly dense, dense.
 - limited, fairly widespread, widespread.
 - of the zones; apical, medium, lower.
 - of the lungs: right, left, both lungs.
9. Other modifications: for example, aortic dilatation, cardiac, pneumothorax, etc.
10. Provisional diagnosis by the radiologist. (Underline the appropriate terms in 6, 7 and 8.)

The merit of this classification is that for the first time, the diversity of the radiographic aspects of the pneumoconioses is stressed without tying them to clinical features, but it can be said to be both too vague and too precise. Too vague, because it gives an incomplete idea of the shape and number of the abnormal shadows; too precise, because they are localized in the apical, sub-apical and lower regions of the lungs.

The American classification (1938)

The second I.L.O. conference on silicosis was held at Geneva in 1938, and classifications of the pneumoconioses were discussed, though none was adopted. An important contribution was SAYERS' description of an American classification drawn up by a number of distinguished experts belonging to different disciplines: clinicians, hygienists, pathologists and radiologists. The classification which they proposed reflected their various preoccupations and took into account both the radiographic features, the histological appearances, the objective and subjective clinical findings and the degree of incapacity for work. Their report constituted a serious attempt at synthesis and correlation of X-ray shadows with the pathology of the pneumoconioses, together with their other aspects. It brings out clearly that the main stages of X-ray abnormality are linear, granular, nodular and agglomerate or coalescent (Fig. 1), but little attempt is made to distinguish the quantitative and qualitative features of the shadows. It shows further that it is not possible to compress all the problems of pneumoconiosis into the narrow limits of one classification, and from that time, further attempts to do so were abandoned.

At this conference IRVINE made some interesting observations about linear, pinhead and medium mottling correlated with histology. For instance, he said that three characteristics of the radiographic findings indicated the presence of silicosis:

- (1) The appearance of an abnormal increase in the linear striation visible in the lung fields, accompanied nearly always by enlargement of the hilar shadows.
- (2) Appearance of definite mottling, that was to say, of small discrete shadows scattered throughout the lung fields, which in simple cases

were usually sharply defined, circumscribed and more or less symmetrically distributed, and in the infective type of case were more irregular in size and distribution. These could be graded into small, medium and large mottling.

- (3) Appearance of larger and diffuse opacities indicative of a definite pulmonary consolidation significant of massive fibrosis of simple silicotic and infective silicotic nature, or due to tuberculosis, infiltration and consolidation.

American Classification

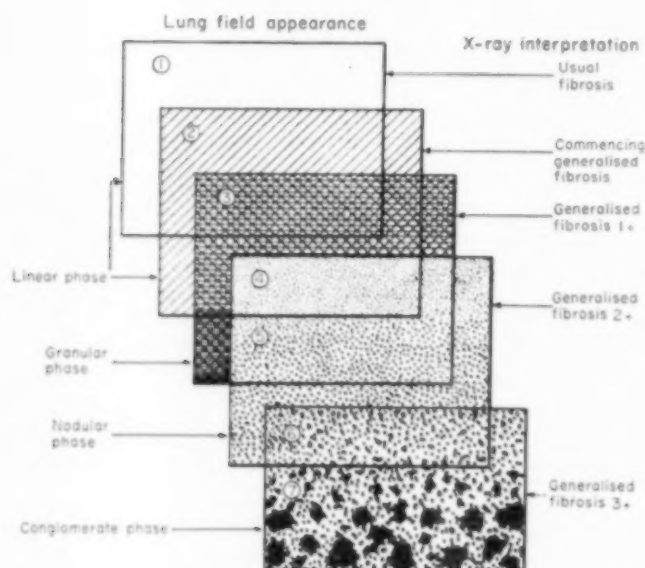


FIG. 1. Scheme of X-ray interpretations.

He went on to say that post-mortem examinations showed that abnormal increase in striation was coupled with an increasing amount of significant palpable macroscopic silicotic nodulation. In 50 per cent of cases in which there was well-marked increase in linear striation, post-mortem examination showed a significant amount of incipient silicosis.

Eck and Hanaut's classification (1944)

In 1944, ECK and HANAUT, in their strictly radiographic classification (Table 1), emphasized the main abnormal shadows seen in the X-ray films, and their coding takes into account both the quantitative and qualitative aspects of such shadows. This is an important classification, because most subsequent ones have been derived from it, and it describes X-ray shadows without taking other considerations into account. It will be seen that their classification includes a linear stage, two types of nodular shadows, and pseudo-tumoral or massive shadows.

TABLE 1. ECK AND HANAUT'S CLASSIFICATION 1944

Qualitative Aspect	Quantative Aspect
O—Normal	
P—Pathological X-ray picture, but not typically silicotic.	
F—Linear Stage	F1—Marked accentuation of the broncho-vascular shadows. F2—A considerable number of linear shadows in addition to an accentuation of the broncho-vascular shadows. F3—Tangled thick linear shadows extending over both lung fields.
M—Micronodular Stage	M1—Some fine nodules scattered throughout two lung fields, but not numerous. M2—Moderate reticulo-nodulation. M3—Very marked reticulo-nodulation.
N—Nodular Stage	N1—Disseminated nodules, with a diameter greater than 2 mm. N2—Numerous disseminated nodules. N3—"Snow-storm" picture.
T—Pseudo-tumoral Stage	T1—Beginning condensation. T2—Well-marked condensation. T3—Pseudo-tumoral shadows.

The Hasselt classification (1948)

In 1948, at the Institut d'Hygiène des Mines at Hasselt, one of us (V. VAN MECHELEN) with BELAYEW, compiled a classification much on the same lines, but which emphasized the importance of the fluffy shadows and the various complications which often accompany the pneumoconioses (Table 2). All the categories may be accompanied by—

TABLE 2. HASSELT CLASSIFICATION (VAN MECHELEN AND BELAYEW) 1948

O—Normal	N—Nodular
SO—Subnormal (a subnormal picture means each film showing a calcified primary infection; reticulation; broncho-vascular shadows or thick peribronchial shadows).	N1—slight or localized N2—moderate N3—marked
M—Micronodular M1—slight or localized M2—moderate M3—marked	CND—Indefinite condensations T—Pseudo-tumoral T1—multiple fluffy shadows T2—pseudo-tumoral shadows with well-defined margins
—active tuberculosis	+ Ta
—cicatrical tuberculosis	+ Tc
—pleural adhesions	+ Pl
—cardio-aortic anomalies	+ Ca
—marked emphysema	+ E

The P.R.U. classification (1949)

In 1949, the Pneumoconiosis Research Unit of the Medical Research Council of Great Britain (P.R.U.) published a classification of the radiographic aspects found in coalminers' pneumoconiosis (FLETCHER, *et al.*, 1949). It had originally been presented in 1948 by DAVIES and MANN at the international congress in London. In this classification (Table 3) pneumoconiotic shadows are divided into

TABLE 3. THE PNEUMOCONIOSIS RESEARCH UNIT (P.R.U.) CLASSIFICATION 1949

Qualitative Divisions		Quantitative Divisions
Main Division	Subsidiary Types	
Simple Pneumoconiosis	Mixed	Category 1—minimal
	Pinhead	" 2—moderate
	Granular nodulation	" 3—marked
	Homogeneous nodulation	" 4—maximal
	Cobweb	
	Chronic bronchitis	
Complicated Pneumoconiosis	Multiple fluffy shadows	Stage A—ambiguous shadows
	Faint massive shadows	" B—massive shadows
	"Cricket ball" shadows	" C—advanced massive shadows
	Bilateral reniform shadows	" D—advanced massive shadows
	"Angel wings" shadows	with pulmonary distortion

two main categories; first the fine shadows caused by simple pneumoconiosis, and secondly the massive shadows due to complicated pneumoconiosis.* The quantitative element is indicated by a number for the discrete shadows (as in ECK and HANAUT's and the Hasselt classifications) and a letter for the massive shadows. In the opinion of these authors, a simple pneumoconiosis progresses regularly in proportion to the amount of dust retained in the lungs, independently of infection, but it is rarely disabling until after category 2 is reached. On the other hand they regard the complicated pneumoconioses or those with massive shadows, as being associated with infection, usually tuberculous. This type of pneumoconiosis continues to develop independently of further exposure to dust, and is usually accompanied by a marked degree of disability. Even if many experts do not share the views of these authors about the pathology of massive fibrosis, the division of X-ray shadows into these two broad groups has become acceptable to a large number of experts. An important feature of the P.R.U. classification is that it is the first one to make no reference to linear and reticular shadows, though all classifications before, and many since, have included linear and reticular stages. HART and ASLETT's classification (1942) of coalminers' pneumoconiosis had a stage of reticulation, and the Hasselt classification also takes this appearance into account.

The Sydney Classification (1950)

At the third international conference of experts on the pneumoconioses held at Sydney in 1950, FLETCHER presented the P.R.U. classification which was adopted,

* This division is reminiscent of that used in South Africa for many years: "simple" and "infective" silicosis.

with some modifications, as an international one. It might be added that there was a good deal of opposition to its adoption, particularly from experts in pneumoconiosis other than that of coalworkers, but it was finally accepted by all but one member of the conference.

The classification is given in Table 4. It will be seen that it differs little from the

TABLE 4. THE SYDNEY CLASSIFICATION 1950

Category 0—Radiographs within normal limits.

Pneumoconiosis with Discrete Opacities

Category 1—In these radiographs a small number of opacities may be seen in at least two anterior rib spaces extending over not more than half of the medial two-thirds of the lung fields.

Category 2—In these radiographs opacities extend over more than half of the medial two-thirds of the lung fields but are sparse or absent in the lateral third.

Category 3—In these radiographs profuse opacities extend over the whole of both lung fields including the lateral third, although they may be sparse or absent above the clavicles.

Category X—These are radiographs with discrete opacities whose appearance does not accord with any of the preceding categories.

In cases where there is an uneven distribution of the opacities in different areas of the lung fields, the category is determined by the most advanced abnormality that is present over at least half of a lung field.

Pneumoconiosis with Coalescent or Massive Shadows

Category A—In these films opacities more than 1 cm in diameter may be seen in one or more areas, commonly coalescing, but not constituting a massive shadow or even density.

Category B—In these films one or more massive shadows are present, extending over less than the equivalent of three anterior rib spaces on either side.

Category C—In these films large massive shadows of uniform density extend over the equivalent of three or more anterior rib spaces on either side.

Category D—In these radiographs one or more massive shadows are present associated with gross distortion of the pulmonary anatomy. The massive shadows may of themselves be such as would be classified as A, B or C in the absence of such distortion.

P.R.U. classification, in that there are two broad divisions: (a) pneumoconioses with discrete opacities; and (b) pneumoconioses with coalescent or massive shadows, but that there are three instead of four categories in "simple" pneumoconiosis. In the report of the conference it was laid down firmly that the word "reticulation" should never be used to describe X-ray appearances, but in spite of this ban, the word has been used since then in most countries with increasing persistency. It is clearly a useful term to describe an X-ray pattern commonly seen in the pneumoconioses.

The Cardiff-Douai classification (1951)

In 1951 the Cardiff-Douai classification (Table 5) was formulated as a result of meetings between the French experts, BALGAIRIES, AUPETIT, DECLERQ, FOUBERT, JARRY and NADIRAS, and representatives of the P.R.U., COCHRANE, DAVIS and FLETCHER. This classification appears to be a compromise between ECK and HANAUT's, that of the P.R.U., and the Sydney classification, in that it joins together the French qualitative and the Cardiff quantitative points of view. Numerals (1, 2, 3)

are used to indicate the numbers of discrete shadows, with letters (p, m, n) to describe their size. As far as the massive shadows are concerned, the small confluent shadows are designated by the capital letter "A", and the larger shadows by "B", "C", and "D", as in the P.R.U. and the Sydney classifications. With the "A" shadows, the small letters p, m and n can be added to indicate the background picture. A question-mark is used (A?) when the background cannot be defined with certainty.

TABLE 5. THE CARDIFF-DOUAI CLASSIFICATION 1951

Appearances not due to Pneumoconiosis		O X
Appearances due to pneumoconiosis	Simple pneumoconiosis, or pneumoconiosis with discrete opacities	I 2P, 2M, 2N 3P, 3M, 3N
	Progressive massive fibrosis or pneumoconiosis with coalescent or massive shadows	Ap, Am, An, A? B C D

Some good collections of standard X-ray films were made, both at Cardiff and Douai. Their use and comparison with the written definitions of the categories have helped considerably in clarifying the methods of applying a classification to the diverse X-ray pictures found in the pneumoconioses in various countries. We have followed closely the discussions between experts in various industrial regions of Europe and we are convinced that any classification must be illustrated with standard films so that it can be applied correctly.

An important modification of the Sydney classification in Germany for use in coalminers' pneumoconiosis is described by SCHILLER and WORTH (1954). It resembles the Cardiff-Douai classification, except that there are three categories instead of four for films with massive shadows. There are other minor differences, e.g. the letter "s" (submiliare) is used instead of "p" to describe the pinhead or punctiform shadows, and the categories of nodular shadows are defined by measurement. Some of the features of this classification were adopted later at the Geneva conference in 1958.

THE NEED FOR AN INTERNATIONAL RADIOLOGICAL CLASSIFICATION

Most of the experts whom we consulted were agreed that there is an urgent need for an international radiological classification of the pneumoconioses so that abnormal shadows can be described and codified. This necessity is felt by clinicians, but even more by epidemiologists, and by industrial doctors and officials who want to know the incidence and progression of pneumoconioses within an industry or a country, and to compare the findings with those collected in different environments and countries. The need is felt similarly by employers so that they can study the efficacy of preventive measures.

All experts whom we consulted were convinced that the radiographic picture

is only one part of the problem of diagnosis, which must be completed by the taking of an occupational history, and by thorough clinical examination together with cardio-pulmonary function studies.

ADVANTAGES AND DISADVANTAGES OF THE SYDNEY CLASSIFICATION

One of our functions as consultants to the I.L.O. was to find out how far the Sydney classification was being used, and what were its advantages and disadvantages. Briefly, we found that it was being used mainly by the Pneumoconiosis Panels (of the Ministry of Pensions and National Insurance) in Great Britain, and in certain sections of Japan, but nowhere else. In the coalmining areas of Europe, its modification, the Cardiff-Douai classification, had been largely adopted. In no country was it being used in connection with industries other than coalmining. Thus it was not truly international. However, its main advantage was said to be its simplicity. It allowed the division of the pneumoconiotic shadows into small and large with subdivisions according to number and size. It was further said that it could be applied by experienced readers of films with results reproducible enough to facilitate international understanding. It could be used in epidemiological research for the study of the progression of the pneumoconioses, and generally it had the effect of causing the experts to use a uniform radiological technique.

In spite of these basic advantages, the Sydney classification presented a number of disadvantages, one being the arbitrary division of each hemithorax into vertical thirds. Experience at the P.R.U. had suggested that the small opacities were seen first in the internal third of the hemithorax, where the antero-posterior diameter of the chest is greater, then in the middle third and finally in the outer third. This view is not confirmed by experience and most experts hold the opinion that the small opacities appear on the films outside the internal third of the hemithorax.

Another defect was the lack of precision of the limits of certain shadows. Thus, the upper limit of the "A" shadows was not defined, and the "B" and "C" shadows were determined by the number of anterior intercostal spaces which they covered, whereas the width of the latter varies from one patient to another.

The size of the small discrete shadows was ignored in the Sydney classification, and though this defect was remedied in the Cardiff-Douai classification, the upper limit of the nodular opacities was not fixed. Again, the Sydney classification did not permit easy classification of multiple fluffy shadows on account of lack of precision in the definitions of Categories A and B which depended at the same time on the area and density of the shadow.

The condemnation of the term "reticulation" by the Sydney conference had not prevented a large number of experts from using a symbol to designate an accentuation of the linear and reticular pattern of the lungs. For some, this accentuation constituted a danger signal, a suspected or actual beginning of a pneumoconiosis; for others, this accentuation had no particular connection with pneumoconiosis, but it was characteristic and frequent enough to warrant a special mention. We shall return later to this question.

At the Sydney conference the symbol "X" was introduced to indicate those "radiographs with distinct shadows in which the picture did not come under categories 1, 2 and 3." There have been varied interpretations of this definition. Some

British experts have used the symbol "X" to indicate an abnormal radiographic image but which was certainly not pneumoconiotic, whereas on the Continent, the same symbol has been used to describe a picture which was probably pneumoconiotic. The necessity for clear definitions of the various symbols used is obvious. Further, a misunderstanding had persisted about the symbol "m" of the Cardiff-Douai classification, which British experts had been using for "mixed" nodulation, whereas on the Continent it was used to specify "micronodulation". Many of those whom we consulted expressed a desire to be able to complete the diagnosis of pneumoconiosis by using symbols representing its commoner complications, and the Sydney classification did not include such symbols.

This brief account of the main criticisms which can be made of the Sydney and similar classifications has been given in order to make clear the modifications introduced into the new Geneva classification of 1958.

Geneva classification (1958)

The Geneva conference in 1958 recognized that the pneumoconioses, by and large, can produce extremely varied radiographic abnormalities, which are difficult to group in a single classification, because they result from the inhalation of dusts or mixtures of dusts of widely differing concentrations and physical and chemical properties. The conference therefore decided to limit their classification to "persistent radiological opacities in the lung fields provoked by the inhalation of mineral dusts". Moreover these constitute the majority of the pneumoconioses. Nevertheless, asbestosis and berylliosis, while they are mineral pneumoconioses, are said to present features different from other pneumoconioses. (From the purely radiographic point of view the abnormalities found in berylliosis can easily come under the classification.)

In the new classification most of the categories and symbols of the Sydney and Cardiff-Douai classifications have been retained, but the significance of certain signs has been modified or made more precise, and certain new symbols have been introduced (Table 6).

TABLE 6. INTERNATIONAL CLASSIFICATION OF PERSISTENT RADIOLOGICAL OPACITIES IN THE LUNG FIELDS PROVOKED BY INHALATION OF MINERAL DUSTS*
(Geneva Classification 1958)

	No pneumoconiosis	Suspect	Pneumoconiosis						
Type of opacity			Linear opacities	Small opacities			Large opacities		
Qualitative features	O	Z	L	p m n			A	B	C
Quantitative features				1 2 3	1 2 3	1 2 3			
Additional symbols	(co)/(cp)	(cv)	(di)	(em)	(hi)	(pl)	(px)	(tb)	

* Including coal and carbon dusts.

DEFINITIONS AND COMMENTS

The object of the classification is to codify the radiological appearances of the pneumoconioses in a simple, easily reproducible way. It is intended to describe the radiographic appearances of the persistent opacities associated with pneumoconiosis, not to define pathological entities, nor to take into account the question of working capacity.

Where there is an appreciable difference in the appearance of the two lungs, the two appearances may be described separately, beginning with the right lung.

No pneumoconiosis	O	No radiographic evidence of pneumoconiosis.
Suspect opacities	Z	Increased lung markings.

Pneumoconiosis

Linear opacities	L	Numerous linear or reticular opacities, the lung pattern being normal, accentuated or obscured.
Small opacities*	<p><i>The following types are defined according to the greatest diameter of the predominant opacities.</i></p>	
	p	Punctiform opacities. Size up to 1.5 mm.
	m	Micro-nodular or miliary opacities. Greatest diameter between 1.5 and 3 mm.
	n	Nodular opacities. Size between 3 and 10 mm.
Large opacities†	A	An opacity having a longest diameter of between 1 and 5 cm, or several opacities each greater than 1 cm, the sum of whose longest diameters does not exceed 5 cm.
	B	One or more opacities, larger or more numerous than those in category A, whose combined area does not exceed one-third of one lung field.
	C	One or more large opacities, whose combined area exceeds one-third of one lung field.

The categorization depends on the extent and the profusion of the opacities.

Category 1: A small number of opacities in an area equivalent to at least two anterior rib spaces and at the most greater than one-third of the two lung fields.

Category 2: Opacities more numerous and diffuse than in category 1 and distributed over most of the lung fields.

Category 3: Very numerous profuse opacities covering the whole or nearly the whole of the lung fields.

Additional Symbols

Recommended additional symbols‡	(co)	abnormalities of the cardiac outline. To be replaced by (cp): cor pulmonale, if this condition is strongly suspected.
	(cv)	cavity.
	(di)	significant distortion of the intra-thoracic organs.
	(em)	marked emphysema.
	(hi)	marked abnormalities of the hilar shadows.
	(pl)	significant pleural abnormalities.
	(px)	pneumothorax.
	(tb)	opacities suggestive of active tuberculosis.

* The choice of order of the symbols is left to the convenience of the physician.

† The background of small opacities should be specified as far as possible.

‡ The use of these symbols is optional.

Thus the symbol "O" does not now mean, as in the previous classifications, a normal thoracic picture, but one which does not show pneumoconiosis. The

symbol "O" may be accompanied by an additional symbol indicating for example the presence of active tuberculosis, emphysema, or an altered cardiac outline.

The introduction, or rather the re-introduction of linear opacities into the classification has been the subject of much discussion. The majority of experts are of the opinion that a marked accentuation of the vascular pattern, or of the peribronchial and interlobular pattern makes the radiographic picture abnormal. However, many hold the view that this common X-ray picture has no statistically demonstrable connection with primary pneumoconiotic lesions. Others again, mainly those who are familiar with the pneumoconioses other than that of coalworkers, consider that a marked accentuation of the linear and reticular pattern constitutes a danger signal of an incipient pneumoconiosis and even in some cases a well-established one.

Investigations specifically directed to this point include the blind reading, by experts from Germany and from the P.R.U., of a number of films of coalminers and non-miners with and without attention to linear opacities, which has been summarized in CONTROLLED CLINICAL TRIALS (1960) and referred to by FLETCHER (1955). This investigation would have been more convincing if a number of films showing nodular opacities from non-occupational causes had been included. If they had been, it is likely that nodular shadows as well as linear ones would have been shown to be not specific. Further, the investigation seems to have been based on the assumption that it is possible to make a diagnosis, as opposed to an inspired guess, from the X-ray film alone. PAUL, in Northern Rhodesia, has found that cases in which he had diagnosed increased linear markings had more pathological abnormality at autopsy than cases not so diagnosed. There may well be a difference between coalminers and men exposed to highly siliceous dusts.

It is pretty generally admitted by most experts that an early pneumoconiosis does not necessarily show abnormal X-ray shadows—in other words that pneumoconiosis may be present when there is a "normal" X-ray film. On the other hand, those familiar with the pneumoconioses caused by dusts with a high free silica content, are convinced that there are special linear opacities in existence which have no connection with the normal vascular pattern of lung shadows.

These linear opacities in certain cases may not be caused by dust deposits or fibrosis, and their certain connections would have to be demonstrated by pathological studies. After many vigorous exchanges of view-points the experts at the Geneva conference decided to compromise, by saying that the linear opacities represented by an "accentuation of the pulmonary pattern" (*accentuation de la trame pulmonaire*) could be designated by the symbol "Z" placed outside the classification.

The linear or reticular opacities which are superimposed in some cases on the long linear (vascular or broncho-vascular) markings were designated by the symbol "L". However, this symbol need not be used in industries where there is exposure to mixed dusts containing relatively little free silica, such as coalmining. Even for the silica risk industries the category was only admitted on a trial basis.

As far as the nodular or discrete opacities were concerned, the conference envisaged simultaneously their qualitative (size) and quantitative (number) aspects. The size of the dominant small opacities was designated by the small letters p, m and n. The symbol p, derived originally from "pinhead", was retained, but a Latin origin was attributed to it, i.e. "punctiform". It corresponds to minute opacities with a diameter less than 1.5 mm.

The symbol *m* defines those "micronodular" or "miliary" opacities whose maximum diameter lies between 1.5 and 3 mm. It is to be no longer used to describe mixed shadows. According to personal preference it can be taken to mean "miliary" or "micronodular" but it should be pointed out that in some countries the term "miliary" is firmly associated with the concept of tuberculous infection. For this reason "micronodular" is often preferred.

The symbol *n* is used to describe those nodular opacities whose greatest diameter is between 3 and 10 mm.

The number of small rounded opacities is relatively difficult to establish, because there is always a desire to combine two different aspects, i.e. their distribution in the pulmonary fields and their profusion.

Category 1 consists of a small number of opacities in an area equivalent to at least two anterior rib spaces and at the most not greater than one-third of the two lung fields.

Category 2. In this category the opacities are more numerous than in category 1, and are distributed over most of the lung fields.

Category 3 is so defined when there are very numerous profuse opacities covering the whole or nearly the whole of the lung fields.

The large shadows are not easy to define. Not only has their area to be taken into account, but also their density (in the radiological sense), their homogeneity and whether their edges are fluffy or well-demarcated. After many trials, it was decided to take into account the diameter of category A shadows, and the areas of categories B and C shadows in relation to the whole area of one lung field. For various reasons the symbol D (indicating distortion of the thoracic organs) appearing in the Sydney and Cardiff-Douai classification was discarded.

Category A applies to a large shadow having a longest diameter between 1 and 5 cm or several opacities each greater than 1 cm, the sum of whose longest diameters does not exceed 5 cm. Thus, some of the multiple fluffy shadows can be classified under this category.

Category B is reserved for one or more opacities, larger or more numerous than those in Category A, whose combined area does not exceed one-third of one lung field.

Category C corresponds to one or more large opacities, whose combined area exceeds one-third of one lung field.

In addition to coding the large shadows, the background of discrete small shadows should also be specified if possible.

Apart from these obligatory categories and symbols which we have just described, the Geneva conference considered that the main complications of the pneumoconioses should be described by optional symbols, which should be placed in brackets to distinguish them from the main symbols.

The optional symbols are given below in alphabetical order:

- (co) Abnormalities of the cardiac outline. To be replaced by (cp); cor pulmonale, if this condition is strongly suspected.
- (cv) Cavity.
- (di) Significant distortion of the intra-thoracic organs.
- (em) Marked emphysema.
- (hi) Marked abnormalities of the hilar shadows.
- (pl) Significant pleural abnormalities.

- (px) Pneumothorax.
- (tb) Opacities suggestive of active tuberculosis.

ADVANTAGES OF THE NEW CLASSIFICATION

The new classification seems to us to have the following advantages.

1. It corrects a number of the imperfections of some of the previous classifications, particularly that of Sydney.
2. It modifies as little as possible the patterns of thought acquired by those who had used the P.R.U. and the Cardiff-Douai classifications, from which it is partly derived.
3. It leaves a greater freedom of application to the experts, by bringing back the linear and reticular shadows (Categories Z and L) and by introducing optional symbols to include the complications of the pneumoconioses. Moreover it leaves to the expert the choice of order in the use of the qualitative and quantitative symbols, (e.g. 2m can also be written m2).
4. It will enable comparative epidemiological studies in various industries throughout the industrial countries of the world.

STANDARD FILMS TO ILLUSTRATE THE CLASSIFICATION

It is generally agreed that it is practically impossible to use a radiographic classification accurately without a set of standard reference films, and in consequence there have been many attempts to produce such standard sets of films. Publications on this subject are accompanied by reproductions of radiographs, mainly of "positive" type and they are of very little help, particularly when the shadows on the original film are not very dense. Since 1942, however, many reproductions have been "negative", but it is always difficult to compare an X-ray film with a reproduction on paper. Sporadic attempts at the reproduction of X-ray films produced unsatisfactory results.

The Pneumoconiosis Research Unit at Cardiff have distributed numbers of sets of standard films of excellent quality, representing the various categories of coalworkers' pneumoconiosis. Preparation of such sets is laborious since the number of exposures for each man has to be strictly limited, and it is necessary to find new subjects of whom a small number of films can be taken.

It was decided that, if standard sets of X-ray films were to be freely available throughout the world, it was necessary to go more closely into the possibility of making satisfactory copies of original films. We began our enquiry at a time when new processes for reproduction were being evolved. Three large photographic firms kindly carried out experimental work at our request, and it was found that copies could be produced so faithful to the original that it was often impossible to distinguish them. Further, the contrast can be so modified that the reproductions bring out the relevant shadows better than in the original film.

The copying processes used by the individual firms varied in detail, but in principle, a master copy on photographic film (the emulsion being on one side only) is made, and from this an unlimited number of negatives on X-ray film (with emulsion on both sides) of the same type as the original film. Electronic methods recently

introduced into the cinema and television industries have helped in the production of copies of high quality.

The fact that an unlimited number of identical reproductions can be obtained from a given radiograph is of primary importance. Verbal descriptions, however precise, have never been able to secure comparable classification of X-ray films by different experts.

In order to make a standard set of films to illustrate the Geneva classification a working party consisting of ourselves and Professor A. L. COCHRANE was appointed to work in close collaboration with the staff of the International Labour Office. We obtained representative films from experts in many parts of the world, and we met on a number of occasions to choose the original films and to supervise their reproduction. We were fortunate to have the help of Professor OOSTHUIZEN of Johannesburg and Professor VIGLIANI of Milan in the choice of films to represent certain categories of the classification.

In our work we met a number of unexpected difficulties. At the outset it appeared to be a simple matter to choose the ideal film to represent a category, but with one or two exceptions we found that ideal films were non-existent. It would have been easier to make a number of collections of standard films to represent the various dusty industries, but we were charged with the duty of making one collection for all types of pneumoconiosis. A "typical" film of coalworkers' pneumoconiosis is not necessarily typical of silicosis in goldminers, or tunnellers in the Swiss Alps, nor yet of the pneumoconiosis found in potters, foundry workers, iron ore miners or in people exposed to the dust of diatomaceous earth. In particular, the distribution and character of the massive shadows may vary markedly from industry to industry.

Another difficulty was found in the copying of the films. Any method of reproduction tends to increase the contrast, so that a slightly "grey" film would give a better final result than one taken with optimum X-ray technique. This fact led to numerous trials with different films, all of which in their original state, would have adequately represented the categories, but which had to be discarded. However, the final set is now complete and copies are available for distribution by the International Labour Office, Geneva.

X-RAY TECHNIQUE RELEVANT TO THE CLASSIFICATION

During our enquiry, we quickly came to the conclusion that it was not feasible to lay down a standard X-ray technique for the taking of chest films. Even if it were possible to standardize the technique, it would have been of little value, because the power and other qualities of X-ray apparatus vary greatly from one place to another. There is also great individual variation in the thickness of the tissues of the chest wall. Moreover, in comparable technical conditions, the personal factor of the radiographer defies standardization. All this explains why, with apparatus of the same power made by the same firm, X-ray films are of unequal quality.

The Geneva conference, however, came to the conclusion that a certain number of minimal technical data could be set down for the taking of chest films of good quality. On the advice of a subcommittee composed of Professors COCHRANE, DMOCHOVSKI and OOSTHUIZEN, the conference made the following recommendations which we quote in full:

- “(a) an X-ray generator with full rectification should be used with a minimum capacity of 200 mA but preferably of 400 mA, equipped with a voltage regulator and synchronous time switch; it is recommended that, wherever possible, an electronic time switch should be used;
- (b) the unit should be fitted with a rotating anode tube with a target of no more than 2×2 mm and equipped, wherever possible, with an adjustable diaphragm to reduce scatter and excessive radiation to a minimum;
- (c) a minimum of 60 kV but preferably of 70 kV is recommended;
- (d) the voltage drop in the current supply should not exceed 10 per cent;
- (e) intensifying screens should be used, of the general purpose type, of medium speed, clean, with a smooth surface, and in close contact with the film at all points;
- (f) a short exposure time of at most 0.1 sec, but preferably of the order of 0.05 sec is recommended;
- (g) films should be of general purpose type, of medium sensitivity, and sufficiently large to cover the whole of the lung fields, including the costophrenic angles;
- (h) the tube-film distance should be fixed and this distance should not be less than 150 cm (5 ft);
- (i) correct centring of the tube and positioning of the patient is important; the tube should be centered on the fourth thoracic vertebra, the subject stripped to the waist and placed in such a position as to bring the scapulae outside the lung fields. The film should be taken in mid-inspiration;
- (j) great care should be exercised with dark-room technique, with insistence on constant temperature processing and the use of fresh film, developer and fixer; it is recommended that a minimum of 5 min be allowed for developing, or longer depending on the type of film used, 10 min for fixing and 30 min for washing; washing should be carried out in running water or in water frequently changed; it is further recommended that wherever possible, automatic processing should be used;
- (k) the use of a photo-timer helps standardization and is therefore recommended;
- (l) the use of a fixed or movable anti-diffusion grid is recommended for use with subjects having an antero-posterior diameter of more than 25 cm.

The quality of a chest radiograph depends on the extent, clarity and contrast of the details that can be seen by the person reading the film. It was generally agreed that the vertebral bodies, but not the intervertebral discs, should be visible through the heart shadow. The discs should be visible through the trachea. It is not intended that this should prevent the use and development of new techniques and the more advanced types of photo-timer.”

RADIOPHOTOGRAPHY IN INDUSTRIAL MEDICINE

The growing importance of radiophotography during the last few years, as a result of improvements in technique, has raised the question of its use in the study and classification of the pneumoconioses by means of miniature films. The earliest

radiographic signs of pneumoconiosis cannot be detected with as much certainty on the small film as on the large film. Moreover, various comparative readings have shown the superiority of the large or standard film and the higher percentage of error which is related to the reduction of the size of the film. Finally, the dose of radiation to the subject is greater with the small than with the large film. The Geneva conference recommended that research into methods for reducing radiation should be pursued. Since then, there have been several papers published on methods of reducing this radiation, notably one by ERNBERGER (1958).

The improvement in radiophotographic technique has come largely from the replacement of lenses by mirrors in the camera. The 70 mm film is thought to be the smallest which can be used for the study of pneumoconiosis, and emphasis is placed on the paramount importance of dark-room technique. Excellent results have been obtained with the 100 mm film. The radiophotographs can be read directly, either with a magnifying glass, or enlarged by projection to the size of a standard film. Classification of the pneumoconioses can be made, even without precise measurement of the shadows, because mental correction can be made by experienced readers.

Radiophotography was introduced in the Belgian coal mines some twelve years ago, and its use has been valuable and economic. But it is realized that the method has its disadvantages, and in doubtful cases a film of standard size must be taken.

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THE DUST IN THE LUNGS OF HÆMATITE MINERS FROM CUMBERLAND

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Abstract—Amount and composition of dust in seventy-two lungs of haematite miners from Cumberland were determined. The lungs were classified into four grades of fibrosis, each with presence or absence of acute tuberculosis at death. The average amount of dust increased with higher degree of fibrosis. The average composition of the lung dust was 81 per cent haematite, 5 per cent quartz and 14 per cent muscovite. In the three higher fibrosis grades the average quartz percentage of the lung dust was slightly but significantly higher in the tuberculosis positive than in the negative cases.

Similarities between coal miners' and haematite miners' pneumoconiosis are pointed out and the role of quartz as causative agent is discussed.

PNEUMOCONIOSIS in haematite miners from Cumberland has been studied by STEWART and FAULDS (1934) and FAULDS and STEWART (1956); in the second paper results of chemical analyses of lung ash were given and it was shown (Table 5) that lungs with fibrosis only, or with fibrosis and tuberculosis, contained on an average 20 g of ferric oxide and 4.5 g of silica. It was not known how much of this silica was present in the form of quartz, and in order to get further information on this point seventy-two lungs were analysed by a combined chemical and X-ray diffraction method. The material for these analyses was composed mainly of dried ground lung which was still available from the work mentioned above, but also included lungs obtained at autopsies between 1954 and 1958.

Haematite deposits in Cumberland are now mined only at Egremont and Millom, and most of the material for this survey came from men who had worked in the Egremont mines, where the ore is dry and hard, and, prior to the reorganization of the mining techniques, the dust content was high. Only five of the lungs examined were from men who had worked in the Millom mines, which lie below the sea and where the ore is damp and soft.

The lungs were classified as before into four grades of fibrosis: 0, +, ++ and ++++. Grade 0 corresponds to what in coal miners is now called simple pneumoconiosis, i.e. lungs which do not show massive lesions. An example is shown in Fig. 1. Grades +, ++ and ++++ refer to increasing size of massive lesions as illustrated in Figs. 2, 3 and 4. Prior to 1947 the grade of fibrosis had been estimated from the post-mortem descriptions assisted by standard microscopic sections, but after this date large sections of lungs were prepared by Professor GOUGH and from these permanent records the amount of fibrosis could be assessed more accurately and the lungs classified accordingly. Large sections were available for post-mortems with numbers above PM 2564 in Table 2.

The lungs were further sub-divided into "tuberculous" or "non-tuberculous"

according to the presence or absence of active tuberculosis with caseation at the time of death. Table 1 shows the number of lungs in each grade. Eight lungs in the series showed carcinoma of the bronchus.

TABLE 1. NUMBER OF LUNGS IN DIFFERENT HISTO-PATHOLOGICAL CLASSES

Grade of fibrosis	Active tuberculosis		Total
	absent	present	
+++	7	6	13
++	11	10	21
+	11	7	18
0	9	11	20
	38	34	72

In haematite mining there is not the same degree of specialization as in coal mining, and most miners are exposed to dust from rock drilling, filling the ore and occasionally shotfiring. Industrial histories were obtained from relatives, trade union officials and employers' records, and were cross-checked wherever possible.

METHODS OF ANALYSIS

Preliminary work showed that the main constituents of the lung dust were haematite (Fe_2O_3), quartz, (SiO_2) and muscovite. Muscovite is a complex silicate belonging to the mica group; it contains about 50 per cent SiO_2 . The lungs were ashed at 450°C . On extraction with 2N HCl, to remove endogenous lung salts, about half the total iron in the ash was also dissolved, and no other acid concentration was found that would remove these salts without at the same time bringing considerable amounts of haematite into solution. The following method was therefore adopted: 300–400 g of lung tissue was dried and ground, and 15–25 g of the ground lung was ashed at 450°C ; the total silica and iron oxide in the ash were determined chemically, the minerals in the ash were identified by the X-ray diffraction powder method, and the quartz content of the ash was measured by G.M. counter diffractometry (GORDON and HARRIS, 1956).

In calculating the dust content of the lungs all iron oxide found was assumed to be haematite. The total silica found chemically was always in excess of the amount of quartz, and this was used to measure the amount of muscovite in the samples. As muscovite contains about 50 per cent of silica, the difference between total silica and quartz was doubled to give the amount of muscovite. The sum of haematite, quartz and muscovite was taken as total dust. Haematite, quartz and muscovite were in this way calculated as percentages of dried lung and, whenever the total dry weight of both lungs was known, as g of dust in both lungs. There were eight lungs in the series for which the dry weight was not known.

The method used over-estimates slightly the amount of haematite, as some of the iron oxide in the lung ash is endogenous. According to GRIFFITHS, *et al.* (1954) human lungs contain 100–150 mg Fe_2O_3 /100 g dried lung (0.1–0.15 per cent). This value is so small in comparison with the total iron oxide found in the haematite miners' lungs that it is of no significance; the average amount of haematite recovered in this series was 8.4 per cent of dried lung, and ranged, with four exceptions in group 0 fibrosis, from 2 to 20 per cent of dried lung.



FIG. 1. Gough section of grade 0 fibrosis.



FIG. 2. Gough section of grade + fibrosis.

RESULTS

The full data are given in Table 2. The lungs are arranged in four separate groups according to the grade of fibrosis; each group is sub-divided depending upon whether or not tuberculosis was also present. In each sub-group the lungs are arranged in decreasing amounts of total dust present. Exposure histories are given as years underground and years between end of dust exposure and death. Occasionally it had been impossible to obtain accurate figures for length of work, and in these cases there is no entry in the column under "dust exposure". The total dust is shown as per cent of dried lung and as a calculated total weight in g. Quartz and iron oxide are shown as percentages of the total dust.

TABLE 2. LUNG DUST ANALYSIS FOR 72 HAEMATITE MINERS

(a) Years in dust

(b) Years between end of dust exposure and death

P.M. number	Age	Dust exposure years		Grade of fibrosis	Tb	Total dust		Percentage of total dust	
		(a)	(b)			In both lungs (g)	% of dr'd lung (%)	Quartz (%)	Fe ₂ O ₃ (%)
1333	50	31	3	+++	—	86.5	21.5	6.0	82.5
448	54	40	0	+++	—	84.0	18.4	6.1	86
237	57	40	3	+++	—	72.4	22.0	4.8	90
576*	49	34	0	+++	—	65.6	19.9	7.2	76
368	50	9	2	+++	—	64.0	11.8	3.1	85
2933	62	41	<1	+++	—	39.8	12.7	3.5	88
3852	61	45	2	+++	—	30.4	4.6	10	59
346	65	43	3	+++	—	79.3	18.5	6.4	85
255	45	30	<1	+++	+	79.2	22.3	5.9	91
698	54	29	6	+++	+	65.2	14.4	5.4	85
3378	71	40	5	+++	+	51.5	9.1	5.8	84
753	49	29	—	+++	+	40.8	11.0	8.4	86
2939†	67	45	4	+++	+	36.5	5.0	6.3	86
2285	58	35	1	++	—	85.0	15.9	6.7	86
1035	44	24	4	++	—	71.6	12.7	5.4	85
1969	47	32	3	++	—	68.7	12.8	4.7	78
1278	65	45	3	++	—	67.0	17.7	4.0	87
3396	73	39	18	++	—	57.0	16.2	2.8	87
1042	74	—	—	++	—	41.7	13.8	4.0	85
4347	60	41	2	++	—	38.7	9.9	4.6	85
7175	75	29	21	++	—	37.8	12.6	5.3	86
7118	80	20+	15	++	—	35.2	17.6	4.3	83
4011	64	20+	16	++	—	30.5	9.4	3.2	86
7171	84	20+	28	++	—	20.4	8.9	6.0	75
4626	75	36	10	++	+	NW	16.6	4.1	86
2564†	64	39	11	++	+	63.4	14.5	5.1	88
669	63	42	1	++	+	48.1	14.5	6.4	69
2379	62	30	11	++	+	45.6	14.0	3.0	84
231	62	22+	2	++	+	45.2	15.9	5.1	87
522	57	28	—	++	+	44.6	8.6	5.1	90
1851	62	25	5	++	+	42.3	9.5	9.5	85
1075	65	30	2	++	+	33.2	10.7	7.8	86
WS4128/									
48	39	22	<2	++	+	31.0	8.6	6.7	86
746	40	24	2	++	+	30.8	6.4	7.8	85
7469	88	42	30	+	—	39.5	14.6	1.7	82
6278	75	30	10	+	—	29.5	11.8	2.6	88

TABLE 2.—(continued)

P.M. number	Age	Dust exposure years		Grade of fibrosis	Tb	Total dust		Percentage of total dust	
		(a)	(b)			In both lungs (g)	% of dr'd lung (%)	Quartz (%)	Fe ₂ O ₃ (%)
6888	71	48	10	+	—	23.6	7.7	2.5	84
4731	66	30	2	+	—	21.6	6.1	1.6	77
7042	80			+	—	19.6	8.5	7.0	81
7470	58	16	28	+	—	12.2	9.6	6.1	83
4950	63	37	2	+	—	11.8	3.4	3.0	84
4162	59	7+	6	+	—	8.1	3.2	3.2	74
		20 gold							
3008	62	40	6	+	—	7.8	4.2	0	86
4733†	62	18	24	+	—	7.7	4.6	4.3	83
5016	66	34	3	+	—	NW	5.7	9.0	61
4638	66	22	22	+	—	36.9	9.1	3.3	79
1895	44	29	1	+	+	31.0	10.5	6.4	84
3414	66		<1	+	+	29.6	7.4	6.3	83
2948	46			+	+	26.8	6.0	9.3	88
4519	44	27	3	+	+	19.5	5.9	6.1	80
4749	57	30‡		+	+	14.4	4.5	2.2	78
4759	47	28	<2	+	+	NW	4.2	5.0	88
4157	70	46	7	0	—	43.7	14.8	6.7	90
7511	71			0	—	NW	9.4	2.0	88
7137	68			0	—	22.4	5.6	7.7	48
667	60	44	2	0	—	20.4	6.2	7.3	78
3110	67	49	<1	0	—	NW	6.2	5.5	76
3559	70	30+	<1	0	—	15.1	5.4	5.7	80
7510	68		0	0	—	NW	9.7	4.2	82
6067	63			0	—	5.0	3.6	7.5	76
3751	62	46	2	0	—	NW	1.6	0.6	93
3782†	66	45	<1	0	+	61.0	11.5	4.4	87
4927	69	43§		0	+	52.0	17.5	12.1	51
1121	50		1	0	+	47.7	15.9	5.3	82
2295	68	30	2	0	+	38.7	12.6	4.3	81
1994	73	40	15	0	+	19.8	5.5	4.2	81
5656	64			0	+	12.9	6.3	5.1	63
7493	58			0	+	NW	5.0	2.6	88
4305	56	20+	14	0	+	9.9	3.9	3.6	81
2974	48	30	<1	0	+	8.3	2.3	5.2	50
912	32	16	2	0	+	3.5	0.6	8.3	67
5833	78	48	16	0	+	3.2	1.05	0	62

NW = no weight.

* with bronchial carcinoma.

† illustrated in Figs. 1 to 4.

‡ 27 years time keeper at bottom of downcast shaft, presumably little dust exposure.

§ includes 13 years stone work—omitted for average dust composition.

Average values of the amount of haematite, quartz, muscovite, mica and total lung dust in the different grades of fibrosis are given in Table 3. The amount of dust decreased regularly from fibrosis grade + + +, through + + to +, and was about the same whether or not tuberculosis was present. Fibrosis grade 0 showed, on an average, as much dust as grade +, but the range of values, from 3 to 60 g, was far wider in this than in any of the other grades. The amounts of dust in grades + + + and + + were significantly higher than in grades + and 0.

TABLE 3. AVERAGE AMOUNTS (IN g) OF DIFFERENT DUST CONSTITUENTS IN THE LUNGS OF SIXTY-FOUR HAEMATITE MINERS FROM CUMBERLAND

Grade of Fibrosis	Without Tuberculosis					With Tuberculosis				
	No. of lungs	Haematite (g)	Quartz (g)	Mica (g)	Total (g)	No. of lungs	Haematite (g)	Quartz (g)	Mica (g)	Total (g)
+++	7	52.3	3.7	6.1	62.1	6	50.9	4.0	3.5	58.4
++	11	42.4	2.4	5.5	50.3	9	36.1	2.6	4.0	42.7
+	10	15.0	0.5	2.6	18.1	6	21.7	1.5	3.2	26.4
0	5	16.3	1.5	3.5	21.3	10	19.3	1.6	5.0	25.9

TABLE 4. AVERAGE COMPOSITION OF DUST IN THE LUNGS OF SEVENTY-TWO HAEMATITE MINERS FROM CUMBERLAND

Grade of Fibrosis	Without Tuberculosis			With Tuberculosis		
	No. of lungs	Haematite (%)	Quartz (%)	No. of lungs	Haematite (%)	Quartz (%)
+++	7	80.8	5.81	6	86.1	6.37
++	11	83.9	4.63	10	84.6	6.06
+	11	80.3	3.73	7	82.9	5.51
0	9	79.0	5.24	11	72.0	5.14

The average quartz and haematite contents of the lung dust are shown in Table 4. The average haematite (Fe_2O_3) content of the lung dust was fairly consistent and it did not differ significantly between tuberculous and non-tuberculous lungs in the same grade. The fact that it was slightly lower in the fibrosis 0 group is due to the presence of a few lungs from Millom with values of 48, 51, 62, 76 and 88 per cent Fe_2O_3 . The average quartz content of the lung dust showed a slight decrease from grade +++ to grade + fibrosis and in each grade the value for lungs with tuberculosis was slightly higher than for lungs without tuberculosis. Excluding the grade 0 lungs, the quartz percentage was 6.0 in those with active tuberculosis and 4.6 in those without tuberculosis. This difference is statistically significant at the 2 per cent level. The average composition of the lung dust in the seventy-two lungs was: haematite, 81 per cent; muscovite, 14 per cent; quartz, 5.1 per cent.

There were only five lungs, PM numbers 2948, 4927, 5833, 6067 and 7137, from the Millom area. In four out of these the quartz percentages were higher and the Fe_2O_3 contents lower than in the other lung dusts. Four of these lungs were classed as fibrosis 0 and one was fibrosis +. The number of lungs is so small that no further comment is justified, but it is interesting to consider why pneumoconiosis is less common among miners from this area. The explanation usually given is that the mines in Millom run out below the sea and the ore is damp and thus less dust is produced in the mines in drilling and blasting. The eight lungs with bronchial carcinoma did not differ as a group in any way from the other lungs as far as amount or composition of dust, exposure history, or age at death were concerned. The oldest man in the series (88 years old) belonged to this group.

Annual dust accumulation rates (total dust in g divided by number of years of exposure) were calculated for the whole series and average values are given in Table 5. The average rate of 1.6 g of dust per year for thirty-one haematite miners

TABLE 5. CALCULATED AVERAGE DUST ACCUMULATION RATES OF HAEMATITE MINERS: g OF DUST PER YEAR

Grade of Fibrosis	Without Tuberculosis		With Tuberculosis		Total	
	No. of lungs	g/year	No. of lungs	g/year	No. of lungs	g/year
+++	6	1.71	6	1.70	31	1.59
++	10	1.59	9	1.43		
+	8	0.60	4	0.95	23	0.69
0	3	0.60	8	0.67		

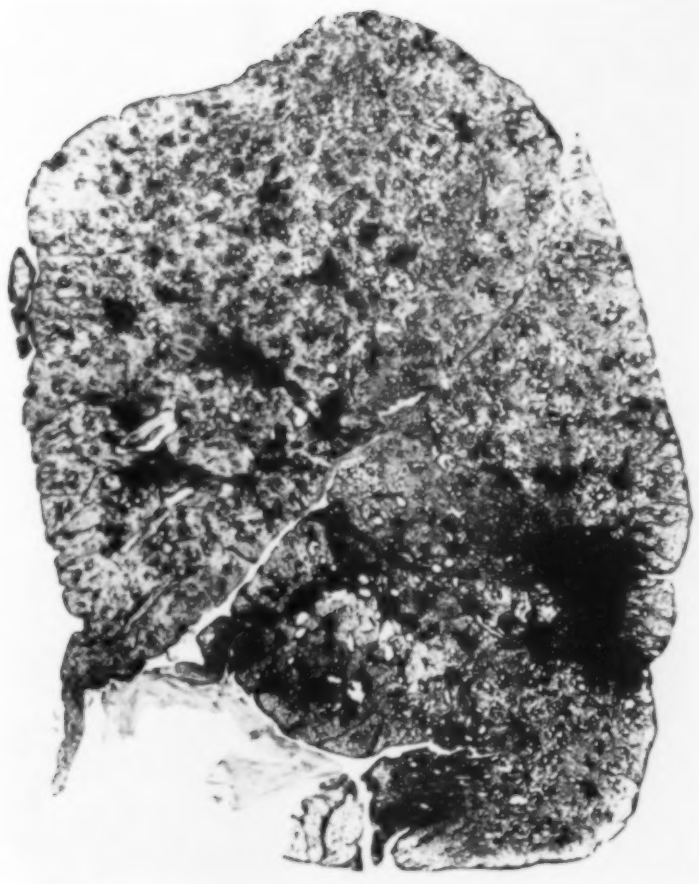


FIG. 3. Gough section of grade ++ fibrosis

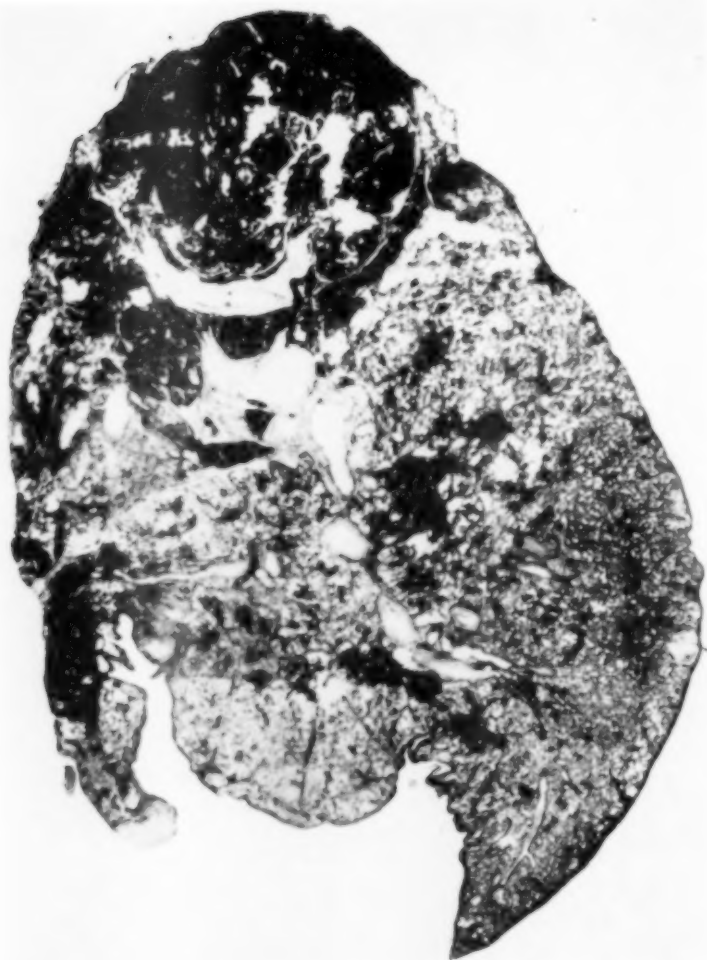


FIG. 4. Gough section of grade +++ fibrosis.

with grades ++ and +++ fibrosis is similar to the average rate found for ten coal miners with massive fibrosis (pathological grade 4) of 1.5 g/year (KING, *et al.*, 1956, Table 17).

In order to have some idea how much soot from the acetylene lamps used in the mines—and from general air pollution—accumulated in the lungs the method of KING and GILCHRIST (1945) of determining "carbon" in lungs was used on average samples of dried lungs of the four fibrosis groups; the results ranged from 1.0 to 1.4 per cent dried lung and this corresponded to between 10 and 15 per cent by weight of the lung dust in the different fibrosis groups.

Averaging the lungs with and without tuberculosis, the average weights of mineral dust and "carbon" per lung were:

Degree of fibrosis	Mineral dust (g)	Carbon (g)
+++	60	6
++	45	4.5
+	21	3
0	24	3

COMMENT

The preceding analyses show that the total amount of dust found in the lungs of haematite miners with massive fibrosis is large, and that the quartz content of the lung dust is comparatively low. The disease is in these respects similar to the pneumoconiosis of coal miners and differs from classical silicosis. Recent work (RIVERS, *et al.*, 1960) has shown that the amount of dust in the lungs of coal workers with simple pneumoconiosis ranged from 5 to 88 g and on an average the quartz content was 2 per cent of the lung dust. In the haematite miners' lungs with grade 0 fibrosis, which corresponds to simple pneumoconiosis, the amount of dust ranged from 3 to 62 g, with an average quartz content of 5 per cent.

The present fibrosis grades +++, ++ and + correspond to PMF in coal workers; grade +++ would probably be read as X-ray category C or D, and grade + as category A (see Figs. 2, 3 and 4). KING, *et al.*, (1956) found in colliers lungs with massive fibrosis between 11 and 150 g of dust with an average quartz content of 2 per cent, and this again is similar to the present range of values although the average quartz content in haematite lung dust is higher, 5 per cent. This figure, however, is still low when compared with classical silicosis where the quartz content is usually above 18 per cent of the lung dust (NAGELSCHMIDT, 1960).

The tuberculosis grading in the present paper refers to terminal appearance of active tuberculosis and the data suggest that this is favoured by quartz, as the small difference, 6.0 per cent, as against 4.6 per cent of total dust, is statistically significant. However, the average amounts of quartz in the combined three fibrosis grades were 2.0 g for "without tuberculosis" and 2.6 g for "with tuberculosis", and their difference was not statistically significant. Thus there is some evidence that in these lungs quartz promoted a terminal active progressive tuberculosis but the evidence is weak. Another factor affecting terminal tuberculosis is specific anti-tuberculous chemo-therapy. Between 1932 and 1945, 50 per cent of seventy-seven

haematite miners' lungs showed tuberculosis. After the introduction of streptomycin, I.N.A.H. and P.A.S. between 1946 and 1959, the percentage with tuberculosis seen in 247 lungs had dropped to 30. The incidence was reduced but not eliminated by these drugs.

The extent to which quartz causes or contributes to the pulmonary fibrosis of haematite miners is difficult to evaluate. Signs of classical silicosis are never found in these lungs, the characteristic lesion consists of varying degrees of massive fibrosis caused by the fusion of irregularly shaped nodules. These nodules have a predilection for location in the upper lobes, usually just under the pleura or in the upper part of the lower lobe. Frequently the fibrosis also has the peculiar feature of involving the adjacent areas of contiguous lobes spreading across the interlobular sulcus.

Thirty years ago it was believed that silica was responsible for the pulmonary fibrosis in haematite miners because chemical analysis gave a high silica content in the lung ash, while microscopical examination showed abundant optically active acicular crystals. Since the danger of silica was well known, the fibrosis was attributed to it and not to the iron-oxide which was considered unimportant and likely to be innocuous. Later, cases of pulmonary massive fibrosis were found in industries associated with a dust hazard in which there was little or no free silica, as in coal trimmers, carbon brush and lamp black manufacturers, and among those working with ferric oxide-silver polishers. Today, therefore, the position is reversed, and the fibrosis is believed to be caused mainly by the presence in the lungs of large amounts of insoluble dust such as carbon or iron oxide, but to be enhanced in proportion to the amount of quartz present. LEONOVA (1958) observed that an iron ore dust with 3 per cent quartz and 17.8 per cent of total silica produced slightly more fibrosis after injection into rats' lungs than other iron ore dusts (which presumably contained less quartz). But most of her work was concerned with showing that the fibrogenic activity of quartz is reduced or delayed by the addition of iron oxide (see also for this effect GROSS, *et al.*, 1960) and not with the effects of small proportions of quartz in haematite. Although definite evidence is lacking, it appears likely that the fairly considerable amounts of quartz in these lungs contributed to the fibrosis and that the dust in haematite mines is the more fibrogenic the more quartz it contains.

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A STUDY OF THE AIRBORNE DUST IN HÆMATITE MINES IN CUMBERLAND

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Abstract—The haematite mines of Cumberland are apparently "safe" with regard to the pneumoconiosis hazard. An attempt has been made to measure the respirable dust concentrations produced by the various mining operations and to estimate an average dust concentration to which the miners are exposed; the results are compared with the "approved" values for dust concentration in coal mines. Results of the compositional analysis of the dust are also presented.

INTRODUCTION

PNEUMOCONIOSIS was first observed in the Northern part of the Cumberland haematite mining area in the 1920's about 10 years after the introduction of dry mechanical drills. The number of men affected rose rapidly in the following years and energetic efforts were made between 1933 and 1936 to introduce effective dust control and medical control (CRAW, 1947). The main dust control measures were improved ventilation, wet drilling, the use of mist projectors with a castor oil/water mixture during shotfiring, and relegation of most of the shotfiring to the end of the shift. There does not seem to have been any substantial change in working methods since that time and there seems to be no evidence that men entering the industry after 1937 have been disabled by pneumoconiosis. It appeared therefore desirable to measure the dust concentrations in this apparently "safe" mining industry and the present paper describes the results of dust measurements made during 1959 and 1960. No attempt was made to carry out a detailed survey such as would be involved in a "random miner" study. Instead, the dust concentrations associated with the various activities (e.g. filling, drilling) were measured and by combining these with the proportion of working time spent in each, a figure giving the order of magnitude of the average dust concentration was obtained.

Methods of working

The mines at which these studies were carried out lie in the Egremont district of West Cumberland; the haematite ores occur as irregularly shaped masses (ore-bodies) within carboniferous limestone strata. The method of extracting the ore is governed by the shape and size of the particular body; the general principal is to extract on a series of levels, the ore remaining between the levels subsequently being collapsed into the lower level, a system known as "robbery" working.

The miners work in small groups of 2-3 men called companies, each company being responsible for its own drilling, filling, timbering, etc. Shotfiring is usually arranged to take place at the end of a shift; as the normal working pattern is one

eight hour shift per day, this allows a period of 16 hr for the shotfiring dust to disperse. Occasional additional shots, e.g. to break up large ore masses brought down by the main shotfiring, take place at meal-break. An oil/water mist projector is switched on at the same time as the shotfiring fuse is lit, and is maintained for 15–30 min. Most of the ore is hand filled into tubs although a few compressed-air operated shovels are in use. Lighting throughout the pits is by acetylene lamps. The "three-dimensional" nature of this type of working makes it difficult to establish a clear ventilation pattern and much of the ventilation in headings and the smaller roadways is fortuitous, depending on the use of drills, rocker-shovels and similar compressed air driven machinery. Workings more distant from the main shaft are more likely to have intake and return roadways along which normal ventilation is maintained.

The time spent by the average miner in the main activities is approximately as follows:

Filling	40–60 per cent
Drilling	35–45 per cent
Shotfiring	5–10 per cent

Sampling techniques

The instruments used in the investigation were the Thermal Precipitator (T.P.) and the "Hexhlet" gravimetric dust sampler (WRIGHT, 1954). The long-running thermal precipitator (L.R.T.P.) (HAMILTON, 1956) was used in some early experiments, but was found to be unsuitable because the dust concentrations were too low and several types of operation were carried out during the course of one shift. It was therefore found to more convenient to use the standard thermal precipitator with its shorter sampling time to obtain samples representative of each type of operation. The samples were counted in the size range 0.5–5.0 μ both before and after ashing. Size-distributions of some of the samples were obtained in 9 size ranges above 0.5 μ with a Patterson-Cawood graticule, again before and after ashing. In addition, a number of samples were evaluated by combined optical and electron microscope counts in 15 size ranges between 0.06 and 10.2 μ by means of the technique described by CARTWRIGHT and SKIDMORE (1953). All the Hexhlet samples were weighed and chemical and X-ray diffraction analyses were made whenever sufficient material was available.

Owing to the absence of a regular ventilation pattern the return airway sampling position used in coal mines was not available; the choice of sampling position depended on the company being studied and the work being carried out; in general positions 5–10 yd behind the working face in small headings were chosen. Furthermore, owing to the relatively low dust concentrations and the mixed nature of the work a sample of dust produced by any one type of operation, and large enough to be weighed accurately, could only be obtained cumulatively during 2–5 shifts; several thermal precipitator samples were taken on each occasion the Hexhlet was running.

RESULTS

Table 1 gives the results of thermal precipitator and Hexhlet dust estimations made at two mines; the figures are classified according to the different operations.

The main emphasis is on filling and drilling dust levels; only 2 figures for shot-firing are given and these are highly dependent on sampling time and position because of the transient nature of the dust cloud produced in this operation. Approximate average values are given in Table 2.

The large scale use of acetylene lamps in these mines increases the airborne

TABLE 1. RESULTS OF DUST MEASUREMENTS IN TWO HAEMATITE MINES

Operation	Location	T.P. count: p.p. cm ³ (0.5-5 μ)	Mean T.P. count: p.p. cm ³ (0.5-5 μ)	Hexhlet concentration (mg/m ³)	Hexhlet/T.P. ratio mg/m ³ per 1000 p.p. cm ³ (0.5-5 μ)
Drilling	Mine F No. 5 Co.	538 (443) 873 (613) 378 (293) 178 (132) 380 (125)	468 (321)	2.4	5.1 (7.5)
	Mine F No. 16 Co.	389 (362) 395 (176)	392 (269)	5.0	12.9 (18.6)
Filling	Mine F No. 5 Co.	65 (44) 65 (66) 92 (79)	74 (63)	0.15	2.0 (2.4)
	Mine F No. 16 Co.	175 (162) 241 (143) 182 (125)	199 (143)	0.6	3.0 (4.2)
	Mine B No. 1 Co.	356 (268) 446 (239) 798 (119)	533 (235)	1.5	2.8 (6.4)
	Mine B No. 58 Co.	537 (444) 103 (83) 136 (‡) 160 (116) 207 (125)	229 (192)	0.6	2.6 (3.1)
	Mine B No. 58 Co.	103 (83) 136 (‡) 160 (116) 207 (125)	152 (108)	0.4	2.7 (3.7)
	Mine B No. 1 Co.	551 (168) 305 (199) 420 (228) 316 (226)	398 (205)	2.8	7.0 (13.7)
Shot Firing	Mine B	8997 (‡)*		14.7	1.6
	Mine F No. 5 Co.	947 (‡)†		—	—

Figures in brackets refer to counts after ashing.

* This is an L.T.R.P. figure. Sampling was begun 10 min before shotfiring took place.

† Taken 30 yd from face; sampling begun 10 min after firing.

‡ Cover slips broken during ashing.

particulate matter because of the carbon particles formed in the combustion process. These are shown by an electron micrograph (Fig. 1) to have the typical appearance of loose aggregates of chains of ultra-fine particles. Owing to their open structure and small size, they may not add much to the gravimetric dust concentration but would increase the $0.5\text{--}5\text{ }\mu$ count appreciably, particularly in the lower size region. As a routine measure therefore, all the T.P. samples were counted before and after ashing at 475°C . In fact, as can be seen from Table 1, the percentage loss of particles by this treatment was very variable, probably owing to additional mechanical losses and decomposition of calcite particles during the treatment and the ratio (unashed T.P. count/Hexhlet concentration) was less variable than the ratio (ashed T.P. count/Hexhlet concentration).

TABLE 2. AVERAGE DUST CONCENTRATIONS IN HAEMATITE MINES

Operation	Respirable Dust		Hexhlet/T.P. ratio (mg/m^3 per 1000 p.p. cm^3) ($0.5\text{--}5\text{ }\mu$)
	Particles/ cm^3 ($0.5\text{--}5\text{ }\mu$)	(mg/m^3)	
Filling	Range 100–500	0.2–1.5	2.8
	Mean 250	0.7	
Drilling	Range 400–500	2–5	7.8
	Mean 450	3.5	
Average of drilling and filling	Range 250–500	2–4	6.0
	Mean 350	2.1	

As smoke particles can be readily distinguished from rock and haematite particles by their appearance in electron micrographs, they can be counted and sized separately; this provides an alternative means of estimating the extent to which each type of dust contributes to the total dust loading. Table 3, which combines the results of several filling shifts, shows that, whereas the number of smoke particles above $0.45\text{ }\mu$ in diameter almost equals that of dust particles, the contribution of the smoke to the total weight of dust is only a few per cent. (This is a slight underestimate as there will be a few smoke particles greater than $1.3\text{ }\mu$ in diameter; these have not been taken into account because the sizing of particles greater than $1.3\text{ }\mu$ was done by optical microscopy where the dust and "smoke" particles cannot be reliably distinguished. One or two larger particles would significantly increase the calculated percentage by weight of smoke and bring it into closer agreement with the observed ash percentage of Hexhlet thimble dusts.)

The size distribution of the dust fraction of the filling sample is plotted in Fig. 2(a) together with that of a drilling sample (2b) and a typical coal mine dust sample (2c) as the logarithm of particle number frequency against logarithm of particle diameter. Curves 2(a) and 2(b) are based on combined counts from optical and electron microscopy, curve 2(c) on optical counts only. The resulting straight line plots show for all three samples a fairly good fit to a power law distribution of the form $(dF/dD) = \alpha D^{-\beta}$ proposed by HAMILTON and KNIGHT (1958). The respective values of β are 2.43, 2.0 and 1.68.



FIG. 1. Electron micrograph of haematite mine airborne dust.

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TABLE 3. COMBINED OPTICAL AND ELECTRON MICROSCOPE COUNT OF A T.P. SAMPLE OF FILLING DUST

Size Class (μ)	Particles per cm^3		Calculated gravimetric concn. ($\mu\text{g}/\text{m}^3$)	
	Dust	Smoke	Dust ($p = 4$)	Smoke ($p = 1.4$)
0.06-0.08	348	138	0.092	0.013
0.08-0.11	671	210	0.446	0.049
0.11-0.16	512	537	0.963	0.353
0.16-0.23	271	230	1.53	0.456
0.23-0.32	198	185	3.15	1.03
0.32-0.45	132	140	5.75	2.13
0.45-0.64	87	108	10.77	4.68
0.64-0.9	53	66	18.54	8.08
0.9-1.3	35	23	44.09	8.06
1.3-1.8	16.5		44.70	
1.8-2.6	9		71.75	
2.6-3.6	3		128.4	
3.6-5.1	3		164.2	
Total ($>0.45 \mu$ for particles)	209	197	494.3	24.86
	406		519.2	

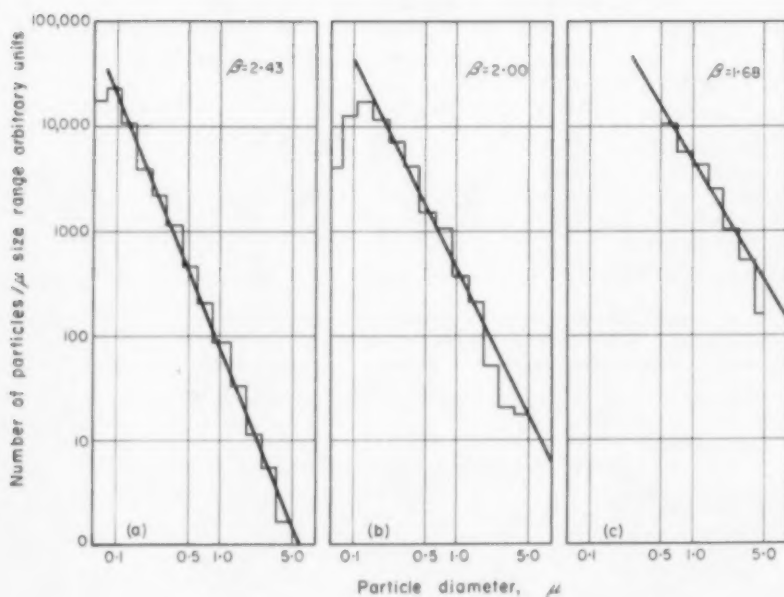


FIG. 2. Size distributions of haematite and coalmine dusts.

Dust composition

A number of Hexhlet thimble samples were examined by partial chemical and X-ray diffraction analysis. Similar analyses were made on -240 mesh fractions of run-of-mine ore and of the finest material from one of the ore crushing plants. From the analyses, the approximate mineral composition was calculated and the data are given in Tables 4 and 5 for Mines F and B, and in Table 6 for crusher fines and samples taken during development work in Mine B. In both mines the airborne dust of respirable size tended to contain less haematite than the run-of-mine material and to have a higher, and often much higher, ignition loss. This was probably mainly smoke from the acetylene lamps used, and is given as "carbon" in Tables 4 to 6.

The airborne dust in development work in Mine B (Table 6), contained calcite as was expected since the rocks are largely limestone. The quartz content of the dusts was usually low, of the order of 1 or 2 per cent, and, in general, the amount

TABLE 4. APPROXIMATE COMPOSITION OF DUST IN MINE F

Constituent	Run-of-mine -240 mesh		Hexhlet Thimble Dust	
	Range	Mean	Range	Mean
Haematite (%)	65-82	75	25-82	60
Quartz (%)	4-25	10	1-3	2
Mica (%)	5-10	10	5-15	10
Calcite (%)	0	0	0-10	5
Carbon (%)	1-2	1	5-37	20

TABLE 5. APPROXIMATE COMPOSITION OF DUST IN MINE B

Constituent	Run-of-mine -240 mesh		Hexhlet Thimble Dust	
	Range	Mean	Range	Mean
Haematite (%)	73-83	80	32-70	50
Quartz (%)	3-10	5	1-2	2
Mica (%)	10-15	15	10-40	20
Calcite (%)	0-1	0	0-5	3
Carbon (%)	1-3	2	10-25	20

TABLE 6. COMPOSITION OF CRUSHER FINES AND OF DUST FROM DEVELOPMENT WORK IN MINE B

Constituent	Crusher Fines		Development Work in Mine B	
	Sample No. 1	Sample No. 2	Run-of-mine	Hexhlet Thimble
Haematite (%)	64	52	10	19
Quartz (%)	8	16	2	3
Mica (%)	12	8	70	9
Calcite (%)	—	—	—	6
Carbon (%)	5	6	15	10

of quartz was less than the amount of total silica found by chemical analysis. The remaining silica was present mainly in the form of the mica muscovite, a complex silicate which contains about 50 per cent SiO_2 . No systematic differences of composition between drilling and filling dusts were observed.

The average composition of lung dust of haematite miners (FAULDS and NAGELSCHMIDT, 1961) showed somewhat more haematite and quartz than the Hexhlet thimble dusts but the differences are small and closer agreement could hardly be expected.

COMMENTS

The history of the incidence of pneumoconiosis in the Cumberland haematite mines has been outlined in the introduction. Pneumoconiosis of haematite miners is similar to that of coal workers in the following features. By radiology, simple and complicated forms can be distinguished and it takes from 20–40 years of exposure to produce the more advanced forms of the disease. The amount of lung dust found in P.M.F. of haematite workers ranges from 20–90 g and its average quartz content is of the order of 5 per cent (FAULDS and NAGELSCHMIDT, 1961). This is double the quartz concentration found in colliers from S. Wales but it is still rather low when compared with 20–50 per cent of quartz found in the lung dust of granite workers or tin or gold miners with silicosis.

As no cases of pneumoconiosis seem to have been reported amongst men who entered the industry after the application of dust control measures of the mid-thirties, and as conditions have been stable since that time, the present dust conditions appear to represent a practical "safe" level for the industry. Average figures for the dust concentrations during filling operations were 250 p.p. cm^3 ($0.5\text{--}5\ \mu$) or $0.7\ \text{mg/m}^3$ and during drilling 450 p.p. cm^3 ($0.5\text{--}5\ \mu$) or $3.7\ \text{mg/m}^3$. Taking the relative amounts of time spent in these occupations as 55 per cent and 45 per cent respectively, the average overall dust concentration is 350 p.p. cm^3 ($0.5\text{--}5\ \mu$) or $2.1\ \text{mg/m}^3$. No allowance has been made for exposure during shotfiring; this is justifiable on the grounds that as such a small percentage of working time is involved, the dust concentration produced (which is very variable), will have little effect on the overall level. As is to be expected, the average dust concentration during drilling is nearly twice that during filling. An unusual feature clearly shown by the size distributions in Fig. 2 is that, although both haematite filling and drilling dusts are much finer than a coal-mine filling-shift sample, the drilling dust is coarser than the filling dust. This observation is supported by the corresponding mass/number ratios in the final column of Table 1; no obvious reason for it can be suggested.

Assuming a value of 2.3 for β in the power law distribution for drilling and filling dust combined, this average concentration of 350 p.p. cm^3 ($0.5\text{--}5\ \mu$) is equivalent to a concentration of 130 p.p. cm^3 ($1\text{--}5\ \mu$). In bituminous coal mines the "approval" limit is defined as 850 p.p. cm^3 ($1\text{--}5\ \mu$) but this is based on a routine of sampling only during the periods of maximum dustiness; this figure corresponds to an "approved" mean concentration for the entire shift of 500–600 p.p. cm^3 ($1\text{--}5\ \mu$). The average value of 130 p.p. cm^3 found for haematite mines is thus about 4 times lower than the approved limit for coal mines. The absence of pneumoconiosis under such low dust concentrations appears reasonable but the value is

so low that it does not throw any light on the question of how "safe" the approved condition in coal mines really are.

Note on mass/number ratios

The mass/number ratio will be defined as the ratio of the mass concentration of a dust cloud in mg/m^3 to the particle concentration in thousands of particles per cm^3 either in the range $1-5 \mu$ (denoted by mass/number ($1-5 \mu$) ratio) or in the range $0.5-5 \mu$ (denoted by mass/number ($0.5-5 \mu$) ratio).

It is of interest to examine the observed ratios of Hexhlet weights to unashed T.P. counts in the final column of Table 1, as, at first sight, these appear very low compared with the corresponding figure for typical coal-mine dust. FAY (1960) gives an observed figure of 21 mg/m^3 (standard deviation, 4 mg/m^3) corresponding to the "approved" level, i.e. a mass/number ($1-5 \mu$) ratio of 24.7 for coal-face samples on all shifts. Another series of tests involving two collieries (S.M.R.E., unpublished data) gave a similar value of 27.3 (standard deviation 7.8) for the mass/number ($1-5 \mu$) ratio. For an average coal mine sample the value of the "p-ratio", i.e. the ratio of the $0.5-5 \mu$ to the $1-5 \mu$ count (FAY and ASHFORD, 1960) can be taken as 2; the corresponding mass/number ($0.5-5 \mu$) ratios, which are directly comparable with the final column of Table 1, would then become 12.4 and 13.6, or, on average, 13.0.

The cut-off characteristics of the Hexhlet elutriator for a given dust depend upon the density, particle size and particle shape of the dust; the more dense a dust, the smaller is the maximum size particle which will penetrate the elutriator and be collected in the thimble. A typical Hexhlet dust from a haematite mine has a density of about 4 g/cm^3 ; a filling dust with a size distribution as shown in Fig. 2(a) should have a mass/number ratio of about half that of a typical coal mine sample and a drilling dust as shown in Fig. 2(b) about three-quarters, i.e. mass/number ($0.5-5 \mu$) ratios of 6.5 and 9.7 respectively based on the figure of 13 for coal mine dust. The observed ratio of 9.0 for drilling operations is in good agreement with theory; the ratio of 2.6 for filling dust is less than half the predicted value. This discrepancy is explained partly by the fact that these ratios are calculated from unashed T.P. counts and therefore include smoke particles. As shown in Table 2 a filling dust may be almost 50 per cent smoke particles by number; these particles, however, add little to the gravimetric concentration, and correcting for them could almost double the filling sample mass/number ($0.5-5 \mu$) ratio; the effect on a drilling sample would be much less pronounced as the proportion of smoke particles is much smaller.

If the size distribution, density and shape factor of a dust are known, it is possible to calculate a rough value for the mass/number ratio. This has been done for the three dusts whose size-distribution are shown in Fig. 2 and the results are given in Table 7 together with the observed values. Again the observed mass/number ratios for the haematite samples are calculated on the unashed T.P. counts which include smoke particles; a calculation based on dust alone, which would be more accurately comparable with the first column of this table would give higher mass/number ratios and therefore higher values for the first two observed/theoretical ratios in the final column.

ROBINS (1954) gives a value of 0.2 for the volume-shape factor of a coal dust of size range $3-16 \mu$ projected diameter and this value has been used in the above

calculations. A recent determination by CARTWRIGHT of S.M.R.E. (private communication) for a lower size-range coal dust gives a rather higher figure (0.25); use of this figure would increase by $\frac{1}{4}$ the theoretical mass/number ratios in the first column of Table 7 and similarly decrease the observed/theoretical ratios in the final column. These would still be considerably greater than one; reasons for this anomaly will be considered in detail in a forthcoming publication (CARTWRIGHT, *et al.*, to be published).

TABLE 7. COMPARISON OF THEORETICAL AND OBSERVED MASS/NUMBER RATIOS

Sample	Theoretical mass/number (0.5-5 μ) ratio	Observed mass/number (0.5-5 μ) ratio	Ratio Observed/ Theoretical
Haematite filling (2a)	2.01	2.6	1.29
Haematite drilling (2b)	2.72	9.0	3.31
Underground coal dust (2c)	4.02	13.0	3.24

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PRODUCTION ET OBSERVATION D'AEROSOLS MONODISPERSÉS APPLICATION À L'ÉTUDE DE QUELQUES PROPRIÉTÉS PHYSIQUES D'ÉTATS DISPERSÉS

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Résumé—La première partie de ce travail traite de la mise au point de générateurs d'aérosols monodispersés.

La seconde décrit différents procédés de visualisation au microscope électronique de particules trop volatiles pour être observables dans les conditions normales.

Dans la troisième partie on compare trois méthodes différentes pour la mesure des particules: mesure au microscope optique, mesure au microscope électronique et mesure de la taille déduite de la vitesse de chute.

Enfin, la dernière partie est une application des méthodes ci-dessus à l'étude de l'agglutination spontanée.

PRODUCTION ET OBSERVATION D'AEROSOLS MONODISPERSÉS

1. Description des Générateurs Utilisés

NOUS avons construit et mis au point trois types de générateurs différents:

(A). Le générateur d'aérosols d'acide stéarique de V. K. LA MER et D. SINCLAIR (1950), dont le principe consiste à condenser de la vapeur sursaturée sur des noyaux de condensation. L'acide stéarique présente l'avantage de donner facilement des aérosols à forte concentration, mais par suite de sa volatilité il a l'inconvénient de ne pas être observable directement au microscope électronique.

(B). Un générateur d'aérosols de silice: dans cet appareil l'aérosol est produit lors de la mise en présence d'un aérosol monodispersé d'eau et de vapeur de SiCl_4 .

(C). Un générateur d'aérosols métalliques à bas point d'ébullition, présentant l'avantage d'être observables directement au microscope électronique. L'inconvénient de ce générateur est de nécessiter la mise en oeuvre de hautes températures, de l'ordre de 1000 °C, avec tous les inconvénients que cela comporte du point de vue des matériaux à employer et de l'étanchéité du système.

A. Production d'aérosols monodispersés d'acide stéarique

Mise au point.—(Voir croquis Fig. 1 et 2). L'acide stéarique est chauffé au-dessus de son point de fusion, à température maintenue constante à moins de 1 °C près, dans un ballon en Pyrex. Un débit constant d'azote pur, sec et dépoussiéré, donc dépourvu de noyaux de condensation, traverse l'acide stéarique liquide en entraînant une certaine quantité de vapeur. Un autre débit constant d'azote pur, sec et dépoussiéré, arrive par le sommet du ballon après avoir traversé un ioniseur (étincelle

* Extraits d'une thèse présentée au Conservatoire National des Arts et Métiers.

jaillissant entre deux électrodes en tungstène) où il s'est chargé d'ions formant noyaux de condensation. Le mélange d'ions et de vapeur est ensuite conduit dans un réchauffeur en Pyrex, chauffé à une température constante égale à 300 °C dans le but d'éliminer toute particule solide d'acide stéarique qui pourrait subsister.

Le mélange est alors entraîné dans une colonne de refroidissement: la vapeur devenant sursaturante se condense sur les ions. L'aérosol ainsi formé est ensuite dilué dans l'air pour éviter une agglutination trop rapide.

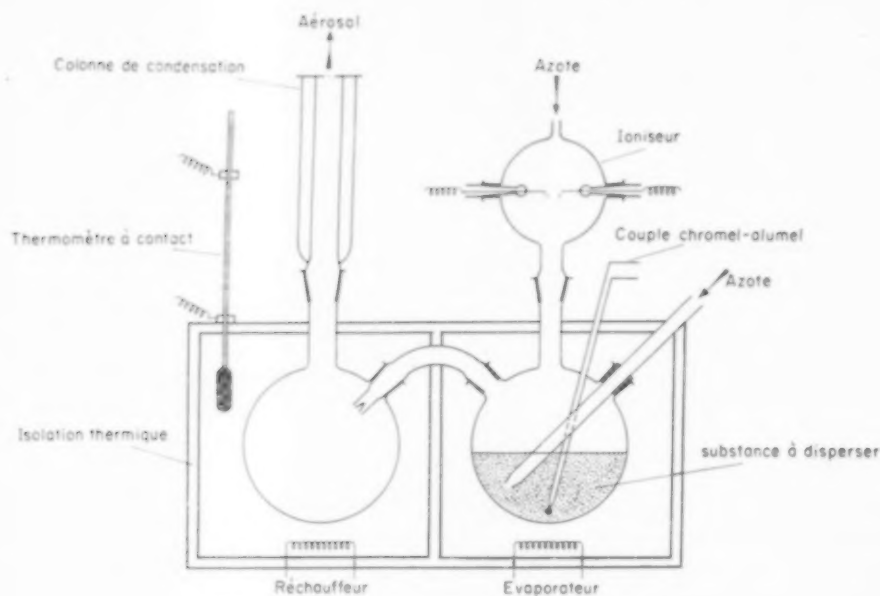


FIG. 1. Schéma du générateur d'aérosols monodispersés.

Pour conduire l'opération avec succès il faut essentiellement:

- Maintenir avec précision la température du bouilleur (régulation automatique du chauffage par "tout ou un peu").
- Maintenir les débits "azote bouilleur" et "azote ioniseur" bien fixes.
- Avoir un "débit d'ions" bien constant.

Le dernier problème à résoudre est celui du réglage des différents paramètres de façon à obtenir des particules de taille déterminée. Le débit d'azote traversant le bouilleur et la température du bouilleur déterminent la quantité de vapeur entraînée par sec, et le débit d'azote traversant l'ioniseur agit sur le nombre de noyaux de condensation non recombinaisonnés arrivant dans la vapeur: plus ce débit est faible, moins l'azote ionisé contiendra de noyaux de condensation.

De plus le "débit d'ions" est fonction de l'intensité traversant l'arc, qui doit donc être maintenue bien constante. En faisant varier cette intensité on dispose d'un autre moyen de modifier de "débit d'ions" arrivant dans le bouilleur.

A titre d'exemple voici les valeurs des paramètres correspondant au cliché n° 3:

Débit d'azote dans l'ioniseur	2 l./mn
Débit d'azote dans le bouilleur	2 l./mn

Air de dilution	30 l./mn
Température du bouilleur	220 °C
Intensité maximum de chauffage du bouilleur	1 A
Intensité minimum de chauffage du bouilleur	0,9 A
Intensité traversant l'arc	9 mA
Tension	6000 V
Taille des particules obtenues	2,5 μ

Production des noyaux de condensation.—Nous avons construit un appareil donnant un "débit d'ions" stable et réglable. Ce montage comprend un alternostat alimentant le primaire d'un transformateur 220–15,000 V. La tension alternative est appliquée aux bornes de deux branches parallèles comprenant chacune un condensateur de 0,1 μ F (32,000 V) et une série de 15 redresseurs 1000 V, 10 mA. La tension redressée est appliquée aux deux électrodes de tungstène de l'ioniseur. Le débit d'ions est réglé en agissant sur la tension primaire du transformateur par l'intermédiaire de l'alternostat.

Production rapide d'un nuage ne comprenant que des particules de deux tailles différentes.—Nous avons mis au point une technique opératoire permettant d'obtenir des aérosols monodispersés de tailles différentes, soit par exemple 6 et 2 μ , avec le même générateur et à une dizaine de min d'intervalle. Nous pouvons ainsi constituer rapidement un nuage ne comprenant que des particules de deux tailles bien définies, ce qui peut être utilisé par exemple pour étudier les rencontres entre particules de tailles différentes dans un nuage soumis à l'action des ultrasons.

Pour avoir rapidement deux nuages homogènes dont le rapport des diamètres des particules soit le plus grand possible nous avons montré que le paramètre à faire varier est le débit d'azote dans l'ioniseur: le principe consiste à utiliser la recombinaison des ions.

Les clichés de la planche n° 4 représentent des particules obtenues à quelques minutes d'intervalle, tous les réglages sont identiques à l'exception du débit traversant l'ioniseur.

Soit 2,0 l./mn pour le cliché 4(a) taille moyenne des particules	2,5 μ
0,75 l./mn " " " 4(b) " " " "	5,6 μ
0,5 l./mn " " " 4(c) " " " "	12,0 μ

Performances du générateur. (1) *Taille des particules:* Au-dessus de 10 μ il est difficile d'obtenir un aérosol bien monodispersé. Le cliché n° 4 (c) montre cet état de chose. Un comptage fait sur une vaste plage au cours du même essai a montré qu'il n'y a que 85 pour cent des particules dans l'intervalle assez large de 10 à 14 μ . Au cours du comptage nous avons même rencontré une particule de 26 μ de diamètre.

Entre 6 et 1 μ le microscope optique montre que la monodispersion est excellente.

La monodispersion est encore réalisée pour des particules d'acide stéarique de diamètre inférieur à 1 μ . Aisi nous avons produit un nuage pour lequel le diamètre moyen et le coefficient de variation étaient les suivants:

$$d_m = 0,62\mu$$

$$CV < 3,3 \text{ pour cent}$$

En résumé, le générateur d'aérosols d'acide stéarique peut fournir avec une monodispersion convenable des nuages de particules dont le diamètre est compris entre $10\ \mu$ et quelques dixièmes de μ . Cette gamme de tailles peut être obtenue en ne faisant varier que deux facteurs: température du bouilleur et débit d'azote traversant l'ioniseur. Il nous a donc paru superflu d'étudier systématiquement l'influence des autres facteurs (débit d'azote traversant le bouilleur—intensité traversant l'arc électrique de l'ioniseur).

(2) *concentration*: En ce qui concerne les concentrations on peut dépasser sans difficulté la valeur de un million de particules de $1\ \mu$ de diamètre par cm^3 .

(3) *forme*: Les particules obtenues sont sphériques.

(4) *charges*: Si une particule port une seule charge élémentaire e_0 sa vitesse de chute sera augmentée ou diminuée suivant le sens du champ H de la quantité:

$$\Delta V = \frac{He_0}{6\pi\eta R}$$

Soit pour une particule de $1\ \mu$ en suspension dans l' "air normal":

$$\Delta V = 28\ \mu/\text{sec.}$$

Une particule chargée, même si sa charge est très faible, subit lors de l'établissement du champ une variation de vitesse importante: la vitesse double à peu près pour une particule de un micron portant une charge élémentaire soumise à un champ de 300 V par cm., il est donc très facile de déterminer si une particule est chargée ou non.

Les particules fournies par notre générateur ne sont pas chargées.

B. Production d'aérosols monodispersés de silice

Le principe est de mettre un aérosol monodispersé d'eau pure en présence de vapeurs de tétrachlorure de silicium.

L'eau décompose instantanément le tétrachlorure avec formation de silice et dégagement d'acide chlorhydrique:



Nous pouvons espérer obtenir par cette méthode des particules de silice de diamètre semblable.

La silice obtenue est à l'état gélatineux et hydraté, elle devient anhydre par calcination, mais par chauffage vers 300°C nous obtiendrons un gel de silice solide et vers 1000°C SiO_2 anhydre.

L'aérosol d'eau est produit par le générateur d'aérosols d'acide stéarique décrit précédemment.

Le générateur de vapeur de tétrachlorure de silicium se compose d'un flacon de tétrachlorure de silicium liquide à 97 pour cent (température d'ébullition 59°C) porté à température convenable au moyen d'un bain d'huile à température régulée par thermomètre à contact à $\pm 0,2^\circ\text{C}$.

Les vapeurs de SiCl_4 sont entraînées par un courant d'azote desséché au préalable par passage sur du Silicagel, et débouchent dans l'aérosol monodispersé d'eau. La réaction est immédiate.

Les résultats semblent être encourageants, nous obtenons des particules qui sont rigoureusement sphériques mais nous n'avons pas réussi à avoir une concentration suffisante pour pouvoir étudier les propriétés de l'aérosol obtenu. En particulier

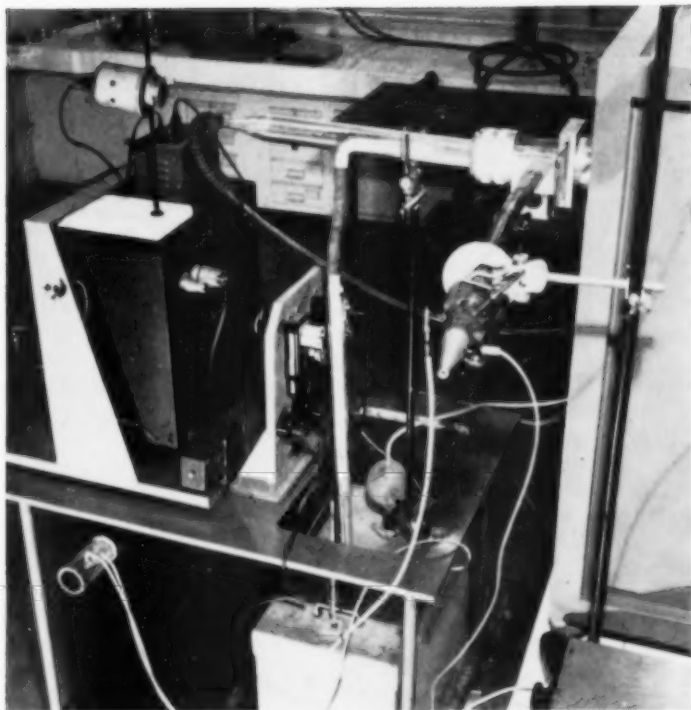


FIG. 2. Générateur d'aérosols monodispersés d'acide stéarique.

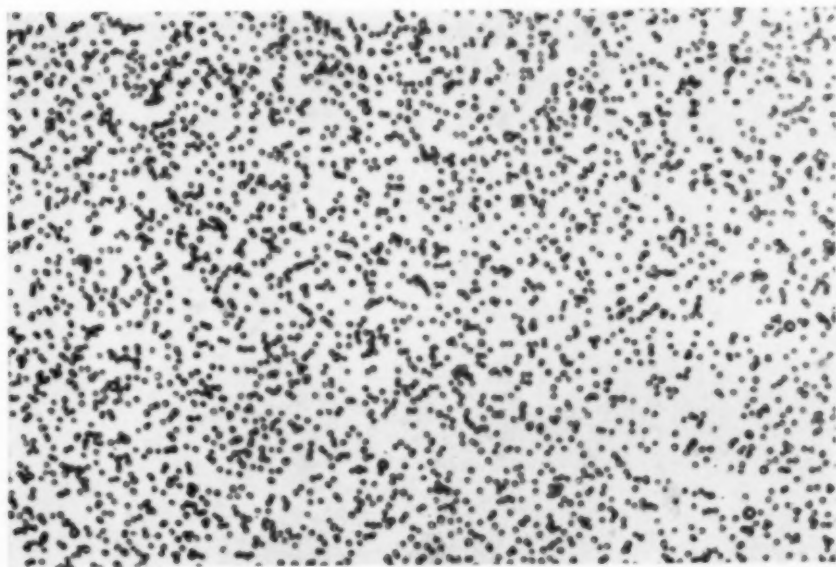


FIG. 3. Particules d'acide stéarique de 2, 5 μ .

[facing p. 278]

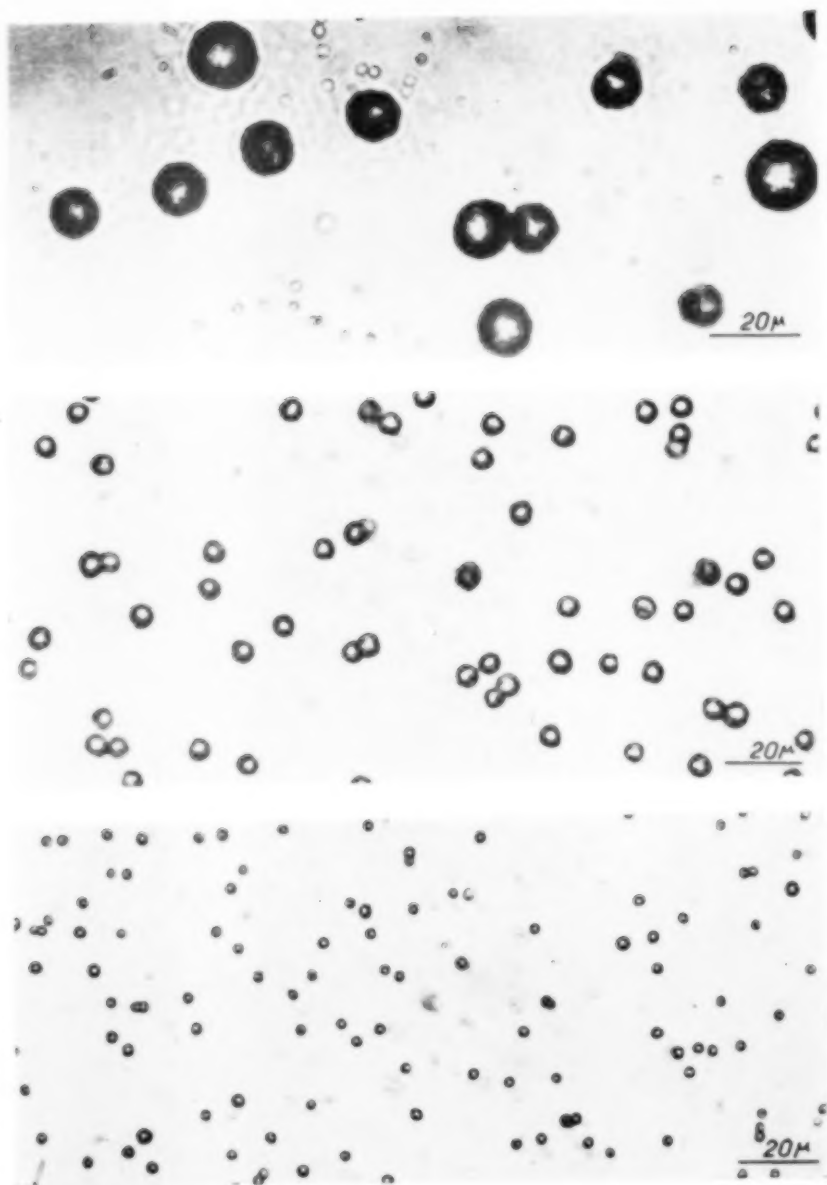


FIG. 4. Aérosols monodispersés d'acide stéarique.

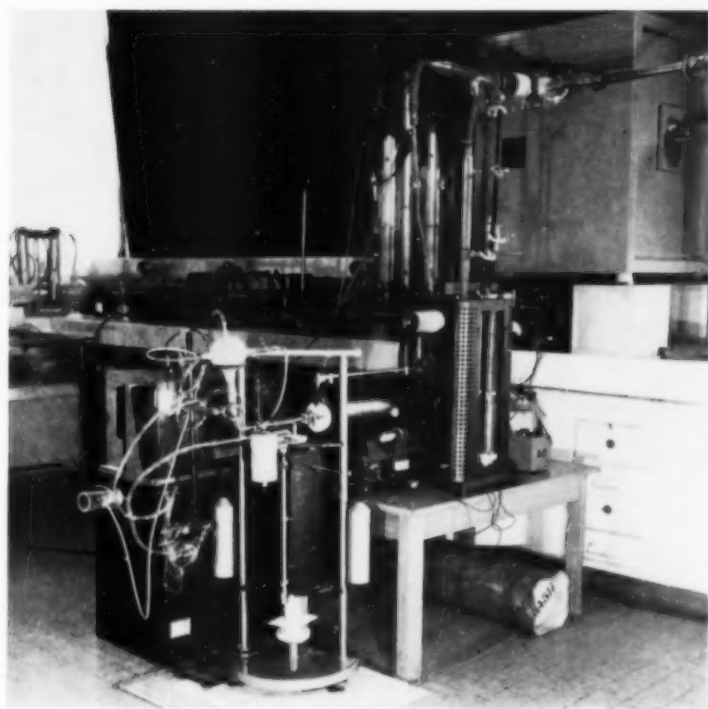


FIG. 5. Générateur d'aérosols monodispersés de métaux à bas point d'ébullition.

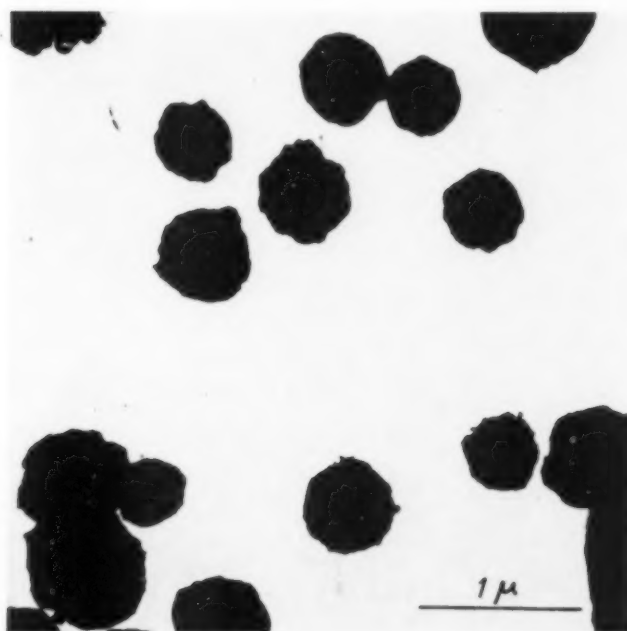


FIG. 7. Particules de cadmium: prélèvement au précipitateur électrostatique.

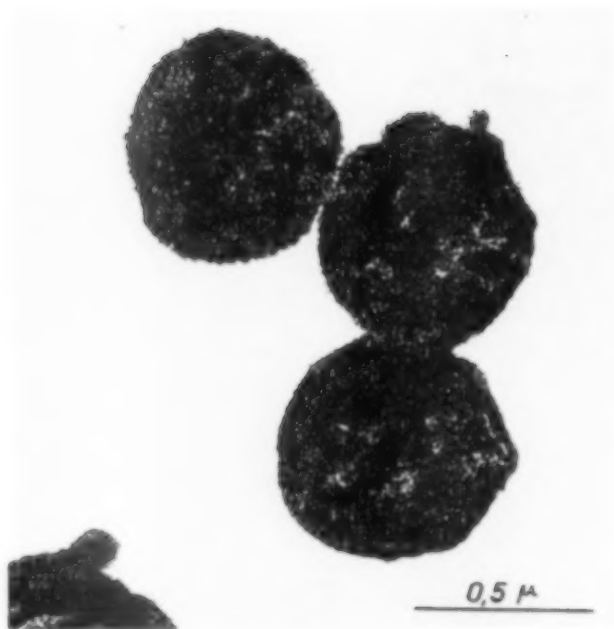


FIG. 8. Particules de cadmium: prélèvement au précipitateur thermique.

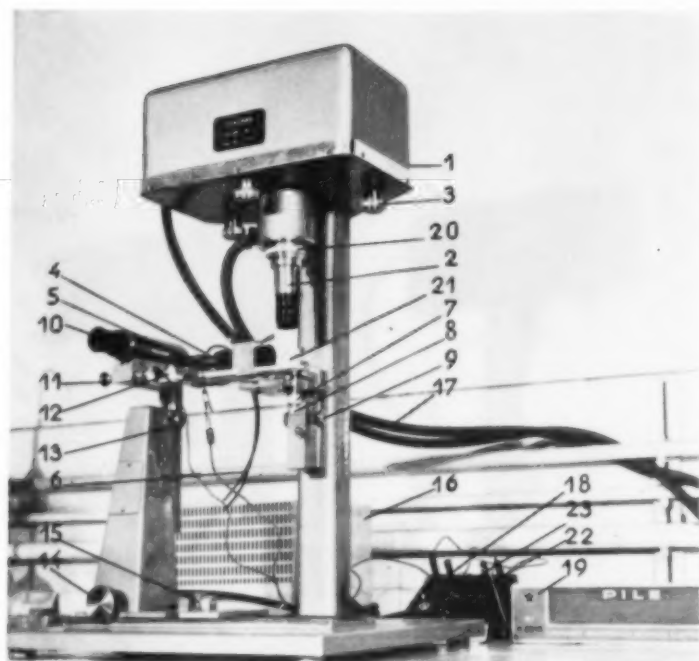


FIG. 9.

- (1) Capot recouvrant la lampe à vapeur de mercure (Philips SP 500—33000 bougies par cm^2 à rayonnement dirigé) et son dispositif de circulation d'eau.
- (2) Tube noirci intérieurement.
- (3) Vis calantes assurant la verticalité du tube (2) contenant le faisceau lumineux incident.
- (4) Objectif focalisant le faisceau lumineux.
- (5) Cuve d'observation.
- (6) Tuyau d'admission et de sortie de la cuve 5.
- (7) Vis de déplacement horizontal transversal de la platine.
- (8) Vis de déplacement horizontal longitudinal de la platine.
- (9) Vis de déplacement vertical de la platine.
- (10) Microscope.
- (11) Vis micrométrique.
- (12) Vis de déplacement rapide horizontal longitudinal du microscope.
- (13) Vis de déplacement rapide vertical du microscope.
- (14) Déplacement rapide transversal du microscope et de son support.
- (15) Déplacement lent transversal du microscope et de son support.
- (16) Transformateur d'alimentation de la lampe SP 500.
- (17) Circulation d'eau.
- (18) Pupitre de commande du champ électrique.
- (19) Piles.
- (20) Fente commandée par une bague graduée.
- (21) Miroir plan à 45 degrés.
- (22) Potentiomètres.
- (23) Commande de l'inverseur.

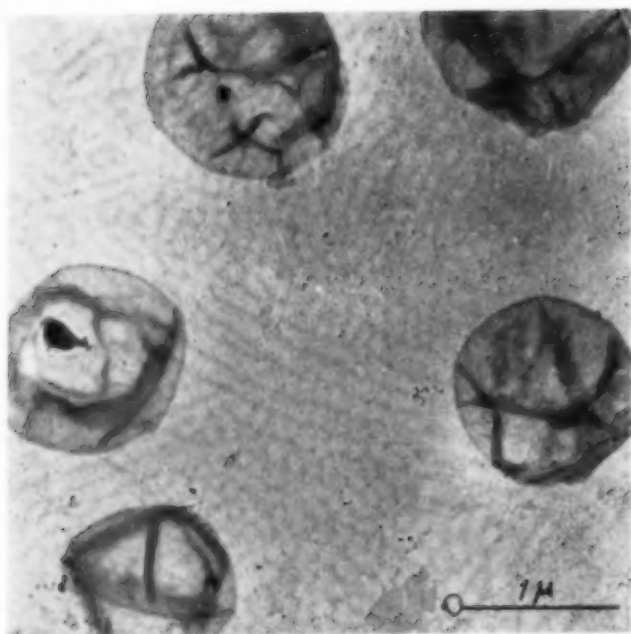


FIG. 10. Moulages entre membranes de carbone.

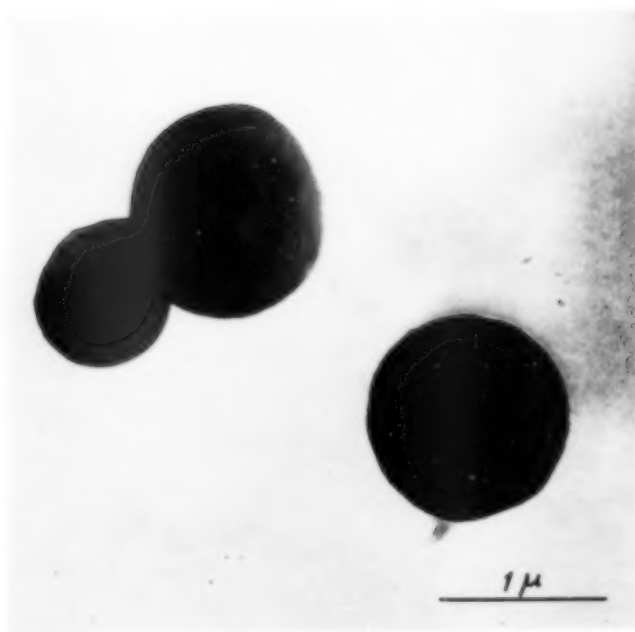


FIG. 11. Réplique au polystyrène.

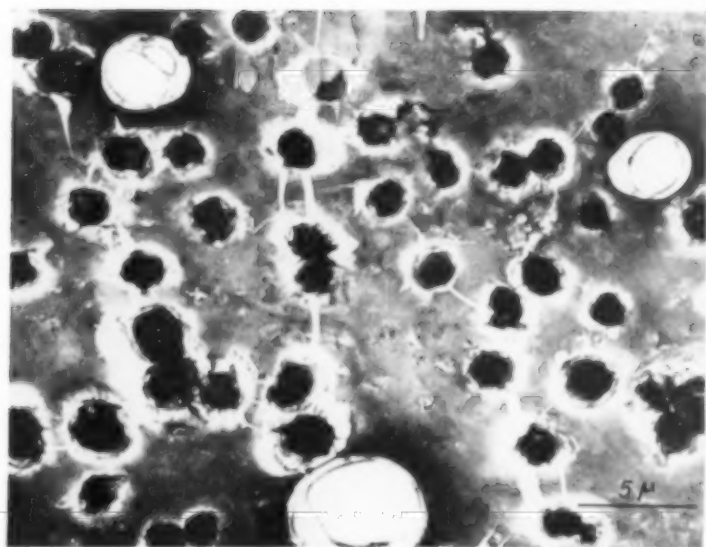


FIG. 12. Réplique au polystyrène—l'alcool polyvinylique est incomplètement dissous.

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nous ignorons si les particules obtenues sont creuses ou pleines, et quelle est exactement leur constitution.

C. Production d'aérosols monodispersés de métaux a bas point d'ébullition: zinc et cadmium

Principe. Nous avons essayé d'appliquer le principe de la condensation de vapeur sursaturée sur des noyaux de condensation à des corps dont les températures de fusion et d'ébullition sont nettement supérieures à celles des corps susceptibles de donner des aérosols monodispersés dans le générateur de La Mer et Sinclair.

Appareillage. (Voir Fig. 5 et Fig. 6). Le bouilleur ou évaporateur et le réchauffeur sont en silice pure transparente ou en métaux réfractaires pouvant supporter les hautes températures mises en oeuvre. Le bouilleur qui contient le métal, est placé dans un four vertical, le réchauffeur dans un four horizontal à régulation automatique.

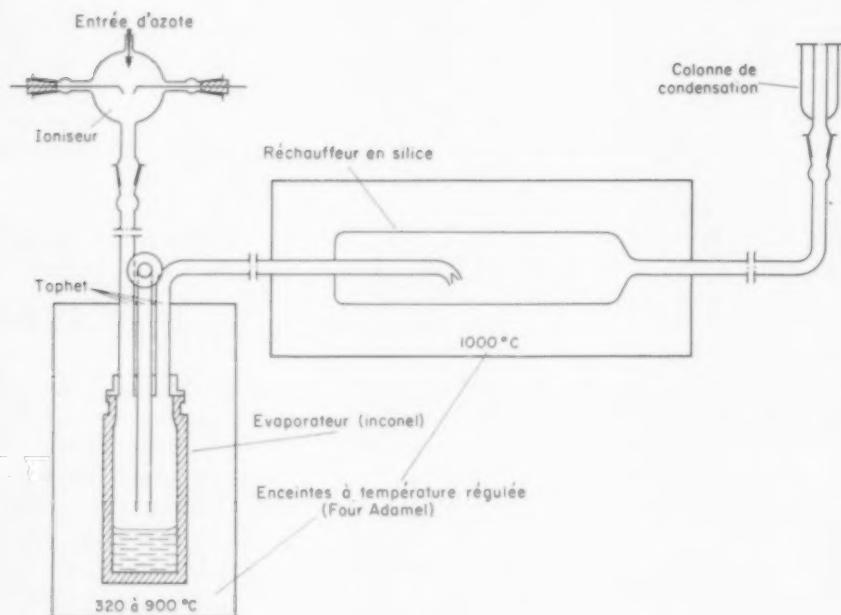


FIG. 6. Schéma du générateur d'aérosols de métaux (zinc, cadmium).

Un couple thermoélectrique platine-platine rhodié commande le four vertical par l'intermédiaire d'un régulateur de température.

Les autres parties de l'appareillage sont identiques à celles utilisées dans le générateur d'aérosol d'acide stéarique.

L'ioniseur, le bouilleur, le réchauffeur et la colonne de condensation étant reliés par l'intermédiaire de rodages plans, les seuls qui ne se bloquent pas à haute température, le point délicat est d'assurer la bonne étanchéité de ces jonctions.

De plus, afin d'éviter soigneusement la formation d'oxyde métallique, l'azote

circulant dans l'appareil est désoxygéné au préalable par passage à chaud sur du cuivre obtenu par réduction de CuO par l'hydrogène.

Toutefois, malgré ces précautions, un examen aux rayons X d'échantillons de poudres récupérées dans le générateur, sur chambre Philips par la méthode classique Debye-Scherrer, a montré la présence d'oxyde en compagnie de métal pur en ce qui concerne les composés cristallisés.

Pour obtenir un aérosol ne comprenant que des particules de métal pur il conviendrait de construire un appareil complètement soudé, en utilisant le produit spécial pour la soudure Silice-Pyrex.

Les différents organes principaux du générateur sont bien visibles sur la photographie Fig. 5.

Resultats. (1) avec le zinc: Une première série d'essais a été faite en fixant la température du bouilleur à 510°C (température de fusion du zinc: 420°C) et celle du réchauffeur à 920°C (température d'ébullition du zinc: 907°C).

Les particules obtenues sont très petites, la monodispersion laisse fortement à désirer mais nous sommes ici encore dans une certaine mesure, maîtres de la taille des particules.

Les prélèvements sont faits au précipitateur électrostatique sur grille de microscope électronique recouverte d'une pellicule de carbone.

L'examen des clichés pris au microscope électronique nous montre que plus il y a de noyaux de condensation, plus les particules obtenues sont petites, ou encore que plus le débit d'azote traversant l'ioniseur est faible, plus les particules obtenues sont grosses.

Enfin comme dans le cas de l'acide stéarique, la modification du nombre de noyaux de condensation donne un effet plus sensible que la modification du débit d'azote traversant le bouilleur.

(2) avec le cadmium: Nous obtenons des aérosols bien monodispersés comme le montrent les Fig. 7 et 8.

Pour les clichés 7 et 8 nous avons employé le précipitateur thermique classique. Dans cet appareil les particules sont précipitées par un champ thermique sur deux lamelles réceptrices circulaires en verre. Quand il s'agit de faire des préparations pour le microscope électronique les lamelles sont au préalable recouvertes d'un film de formvar; une fois les particules recueillies ce film est séparé de la lamelle sur un plan d'eau pure. Pour faciliter l'amorçage de cette séparation on attaque faiblement le bord de la lamelle par une solution d'acide fluorhydrique.

Les particules obtenues ont une forme pseudo sphérique dérivée de la forme hexagonale; elles sont très opaques sur le cliché 7, beaucoup moins sur le cliché 8 où elles semblent avoir été abimées par oxydation ou par action de l'acide fluorhydrique.

Pour les conditions suivantes de fonctionnement:

température du bouilleur	:	520°C
température du réchauffeur	:	1050°C
intensité traversant l'arc	:	6 mA
débit d'azote traversant l'ioniseur	:	2,1 l./m
débit d'azote traversant le bouilleur	:	0 l./m

on a obtenu des particules dont le diamètre de fréquence maximum était de $0,56\ \mu$ avec un coefficient de variation inférieur à 17 pour cent.

En raisonnant par analogie nous avons imaginé un générateur d'aérosols monodispersés de zinc et de cadmium. Ce générateur a donné satisfaction. Il peut constituer un procédé de fabrication original d'aérosols ou de poudres métalliques homogènes.

Il est permis de penser que la production d'aérosols monodispersés par condensation lente et contrôlée de vapeurs de corps purs sur des noyaux de condensation, qui a donné de bons résultats pour des corps aussi différents que le cadmium—corps simple, métallique, bon conducteur de la chaleur et de l'électricité—et l'acide stéarique—acide gras en C^{18} , mauvais conducteur de la chaleur et isolant électrique—est un procédé général qui doit s'appliquer à n'importe quel corps pur, non décomposable par la chaleur, pourvu que les questions de résistance des matériaux aux hautes températures soient résolues.

2. Observations des Aérosols Obtenus

A. Appareil de visualisation

L'observation des particules en suspension dans un gaz est faite au moyen d'un appareil inspiré du montage de TAUZIN (1943, 1944a et b), utilisant la méthode de Zsigmondy, qui permet l'examen de particules ultramicroscopiques.

La source lumineuse est constituée par une lampe à vapeur de mercure haute pression SP 500 à rayonnement dirigé. L'appareil fonctionne soit en éclairage vertical, soit en éclairage horizontal, le passage d'un dispositif à l'autre se faisant par une manipulation rapide. Il permet de photographier les trajectoires.

L'interprétation des clichés et des observations directes est classique (TAUZIN, 1943, 1944a et b; WHYTLAW-GRAY et PATTERSON, 1932a) et nous n'en rappellerons pas le principe. Les observations permettent de déterminer la vitesse de chute, la vitesse de photophorèse, l'amplitude du mouvement brownien, le nombre de charges électriques élémentaires, le diamètre et la densité de chacune des particules observées.

L'appareil peut donner également une idée précise de la monodispersion d'un nuage. Il est représenté sur la Fig. 9.

B. Observation au microscope électronique de particules d'acide stéarique

L'observation directe de particules d'acide stéarique au microscope électronique est impossible car ce produit se vaporise sous l'action combinée du faisceau d'électrons et du vide régnant dans le tube du microscope.

Moulage entre deux membranes de carbone. Nous avons d'abord essayé de voir les particules au microscope électronique en les emprisonnant entre deux pellicules de carbone produites par volatilisation sous pression réduite.

A la sortie du générateur l'aérosol est précipité électriquement sur une membrane de carbone portée par une grille de microscope électronique. La préparation est ensuite recouverte d'une seconde membrane de carbone, la volatilisation du carbone dans le groupe à vide étant faite dès que la pression le permet pour éviter autant que possible l'évaporation des sphères d'acide stéarique. Enfin la pression est abaissée au maximum par mise en action de la pompe à diffusion. Nous obtenons alors une préparation où subsiste seul le squelette des particules comme le montre la Fig. 10.

Cette méthode ne permet pas la mesure des tailles des particules car les squelettes se déforment. Toutefois, elle permet de dénombrer les particules constituant un agrégat; par suite, elle est utilisable pour étudier la coagulation d'un aérosol homogène dont la taille des particules a été mesurée par une autre méthode.

Réplique au polystyrène. Les particules recueillies sur une lame de verre, dans un précipitateur électrostatique, sont recouvertes d'une solution d'alcool polyvinyle dans de l'eau distillée saturée d'acide stéarique. On laisse sécher à l'air, la solution d'alcool durcit. Quand le durcissement est suffisant on décolle la pellicule qui a englobé les sphères d'acide stéarique. L'alcool polyvinyle étant parfaitement insoluble dans les carbures aromatiques, on lave la préparation au benzène qui dissout complètement l'acide stéarique sans abîmer la membrane qui présente alors en creaux l'empreinte des particules.

La préparation est alors trempée dans une solution de polystyrène dissous dans le benzène qui pénètre dans les alvéoles de la pellicule d'alcool polyvinyle. On laisse sécher à l'air: le benzène s'évapore en abandonnant le polystyrène qui vient former une pellicule très mince à la surface de l'alcool polyvinyle moulant ainsi l'empreinte des particules d'aérosol.

On découpe alors la préparation en petits carrés de 2 mm de côté que l'on projette sur de l'eau distillée; l'alcool polyvinyle se dissout complètement dans l'eau et il surnage à la surface une membrane de polystyrène présentant en relief l'empreinte des particules. Il ne reste plus qu'à recueillir les morceaux de membrane flottant à la surface de l'eau sur des grilles de microscope électronique pour obtenir la préparation définitive. (Voir les Fig. 11 et 12 obtenues avec des solutions de polystyrène de concentrations différentes. Sur la Fig. 12 l'alcool polyvinyle n'a pas été complètement dissous.)

Ces préparations observées au microscope électronique montrent des particules déformées dont les tailles sont systématiquement inférieures aux tailles mesurées par une autre méthode; ce procédé n'est donc pas valable. En outre, les particules ne sont plus de la même taille et le nuage paraît hétérogène. Ceci est dû à la pénétration inégale du polystyrène dans les alvéoles de membrane d'alcool polyvinyle.

Nous avons supprimé cet inconvénient en injectant le polystyrène sous pression.

La membrane d'alcool polyvinyle est enfermée avec une solution de polystyrène dans le benzène à 1 pour cent à l'intérieur de la cellule d'un microporosimètre. Une pression de 20 kg/cm² est alors appliquée de façon à faire pénétrer le polystyrène dans la totalité du volume des alvéoles de la membrane.

Nous obtenons au microscope électronique des images bien sphériques prouvant que la réplique est bonne, mais dans un très grand nombre de cas les tailles sont encore diminuées. Le moulage à l'alcool polyvinyle semble être en cause: y-a-t-il dissolution de l'acide stéarique dans la solution (la solubilité de l'acide stéarique dans l'eau est de 0,34 mg/cm³) malgré la précaution prise de saturer préalablement l'eau distillée d'acide stéarique, ou bien la contraction de l'alcool polyvinyle pendant sa "prise" diminue-t-elle la grandeur des alvéoles?

Métallisations. Comme pour le moulage entre deux membranes de carbone, à la sortie du générateur l'aérosol est précipité électriquement sur une membrane de carbone portée par une grille de microscope électronique. On porte alors la

grille dans l'appareil d'ombrage où elle est recouverte d'une mince couche métallique, dès que la pression est descendue à 0,00025 mm de Hg.

3. *Mesure de la Taille des Particules—Résultats des Mesures et Comparaisons des Méthodes*

Les méthodes employées sont les suivantes:

- (A) Mesures sur clichés agrandis pris au microscope optique.
- (B) Mesures déduites de la vitesse de chute.
- (C) Mesures sur micrographies électroniques.

Par souci de précision la comparaison "vitesse de chute—microscopie électronique" a été faite sur des particules trop petites pour que la microscopie optique soit valable. D'autre part la comparaison "microscopie optique—microscopie électronique" porte sur des particules trop grosses pour que la mesure de la vitesse de chute dans notre appareil de visualisation soit précise.

Nous avons donc comparé les méthodes deux à deux.

Après avoir constitué quatre nuages homogènes la taille des particules de chacun d'eux a été mesurée par les deux méthodes à comparer.

A. *Mesure sur clichés pris au microscope optique*

Les clichés ont été pris au microscope sur film de 35 mm. Un tirage est effectué au format 12×18 cm. Le diamètre de l'image des particules est alors mesuré sur cet agrandissement.

B. *Mesure du diamètre déduite de la mesure de la vitesse de chute par application de la Formule de Cunningham*

Les mesures ont été faites au moyen de notre appareil de visualisation suivant la méthode classique.

La densité est connue: pour une particule d'aérosol d'acide stéarique elle est égale à la densité de l'acide stéarique compact, ce qui est loin d'être le cas pour les aérosols de métaux (WHYTLAW et PATTERSON, 1932b).

C. *Mesure sur clichés pris au microscope électronique*

Les préparations métallisées suivant la méthode classique et la grille étalon du microscope électronique sont photographiées successivement de façon à éliminer toute incertitude importante sur le grandissement du microscope. La grille étalon comporte 28,800 lignes par pouce de 25,4 mm soit 0,882 μ par interligne.

Résultats. Le Tableau 1 rassemble la totalité des résultats obtenus en ce qui concerne le diamètre moyen des particules.

On peut conclure que les différentes méthodes donnent des mesures comparables pour les tailles auxquelles elles sont applicables.

Il est donc possible, par ces méthodes, de mesurer le diamètre des particules d'acide stéarique tant que ce diamètre est supérieur à quelques dixièmes de μ .

D'autre part le fait qu'il ait été possible de déterminer convenablement le diamètre de fréquence maximum, ou le diamètre moyen des particules d'un nuage, par un nombre assez réduit de mesures, illustre l'intérêt qu'il y a à utiliser un aérosol monodispersé dans ce genre d'étude.

TABLEAU 1. DIAMÈTRE DES PARTICULES

Nuage N°	Mesures au microscope optique	Mesures déduites de la vitesse de chute	Mesures au microscope électronique
1	1,7 μ	1,7 (4) μ	—
3	2,3 μ	2,3 (3) μ	—
4	3,5 (8) μ	—	3,4 (5) μ
5	—	0,78 μ	0,81 μ

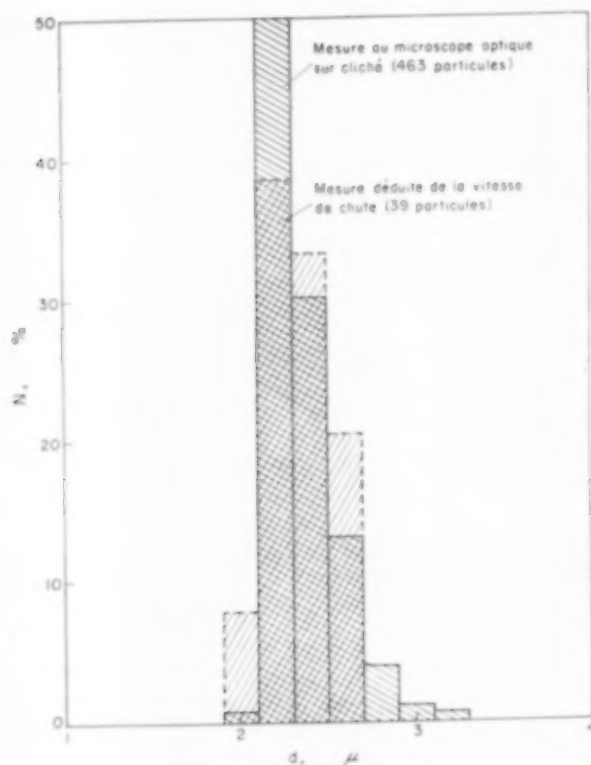


FIG. 13. Répartition des diamètres—nuage n° 3.

TABLEAU 2. COEFFICIENT DE VARIATION

Nuage N°	Mesures au microscope optique	Mesures déduites de la vitesse de chute	Mesures au microscope électronique
1	12,5 %	11,2 %	—
3	9,3 %	6,5 %	—
4	3,9—3,9—5,5 %	—	5,4 %
5	—	12,7 %	11,5 %

Il est encore remarquable de constater que le coefficient de variation des diamètres calculé pour un nuage donné, est le même quel que soit la méthode employée pour la mesure. Le Tableau 2 illustre ce point.

Une comparaison plus détaillée des résultats obtenus peut être faite en juxtaposant les diagrammes de répartition statistique obtenus dans différents cas (Fig. 13 et 14).

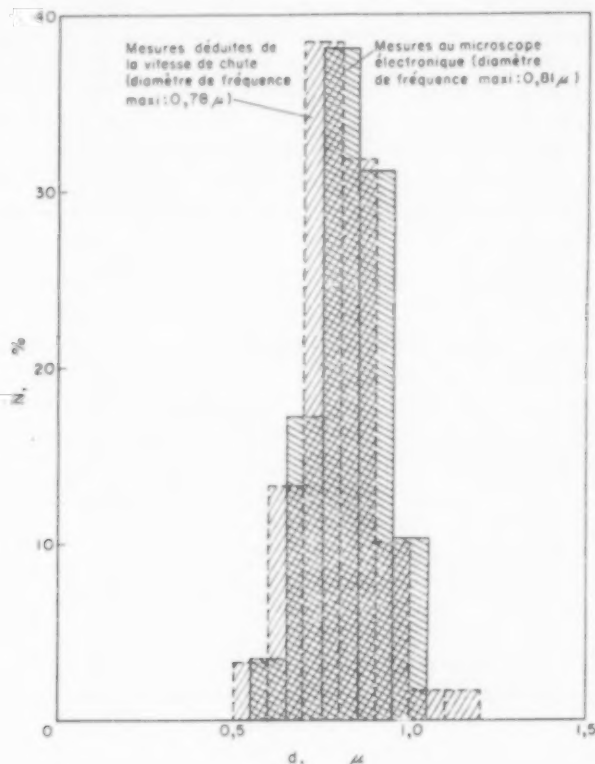


FIG. 14. Répartition des diamètres.

4. Remarque sur l'Agglutination Artificielle d'un Aérosol au Cours de son Prélèvement au Précipitateur Electrostatique

Au cours de notre étude nous avons eu l'occasion d'utiliser un précipitateur électrostatique et nous avons cru remarquer que celui-ci conduisait à des prélèvements contenant beaucoup plus d'agglomérats que le précipitateur thermique, c'est-à-dire qu'un prélèvement au précipitateur électrostatique donne une idée fautive de l'état d'agglutination d'un nuage.

Pour préciser ce point nous avons prélevé à l'aide des deux appareils un certain volume d'un même nuage de particules de cadmium. Les deux préparations ont été photographiées au microscope électronique, en prenant pour chaque préparation une vingtaine de clichés de plages situées côte à côte pour pouvoir reconstituer, en accolant les clichés, la photographie d'une grande surface de chacun des deux prélèvements. Nous avons obtenu les résultats suivants:

Au précipitateur électrostatique, 52 pour cent des agglomérats ne contiennent qu'une particule, 16,4 pour cent des particules sont isolées, et il y a en moyenne 3,17 particules par agglomérat.

Au précipitateur thermique, 74,5 pour cent des agglomérats ne contiennent qu'une particule, 37,5 pour cent des particules sont isolées, et il y a en moyenne 1,99 particules par agglomérat.

Par suite, les prélèvements au précipitateur électrostatique ne donnent pas une image fidèle du nuage du point de vue de l'état d'agglutination, le précipitateur agglutinant artificiellement les particules qu'il prélève.

On peut expliquer ce phénomène de la façon suivante: les particules conductrices placées dans le champ intense du précipitateur électrostatique sont polarisées par influence; comme les concentrations des nuages utilisés sont très élevées, la distance moyenne entre deux particules est faible, et les forces d'attraction électrique donnent naissance à une augmentation de la probabilité de rencontre des particules.

UTILISATION D'UN AÉROSOL MONODISPERSÉ POUR L'ÉTUDE DE L'AGGLUTINATION SPONTANÉE

1. Théorie de l'Agglutination*

A. Aérosol homogène en air calme

La théorie de l'agglutination d'un système dispersé est due à SMOLUCHOWSKY (1918). Si on introduit dans la formule de Smoluchowsky la valeur de la constante de diffusion établie par EINSTEIN (1905)

$D = (RT/N)B$, B étant la mobilité calculée par Stokes-Cunningham,

$B = (1/6\pi\eta r)[1 + A(\lambda/r)]$, λ le libre parcours moyen.

On arrive finalement à l'équation différentielle:

$$-\frac{dn}{dt} = \frac{RT}{6\eta N}(S_1 + S_2) \left[\frac{1 + A(\lambda/r_1)}{r_1} + \frac{1 + A(\lambda/r_2)}{r_2} \right] n^2$$

S_1 et S_2 étant les rayons des sphères d'influence des deux particules diffusantes.

On peut aller plus loin dans le cas où le nuage est homogène: c'est-à-dire quand

$$r_1 = r_2 = r$$

on peut alors poser $S_1 = sr_1 = sr$; $S_2 = sr_2 = sr$

$$-\frac{dn}{dt} = \frac{2RT}{3\eta N}s[1 + A(\lambda/r)]n^2$$

Si les sphères ne s'assemblent que dans le cas où elles arrivent au contact:

$S = 2r$ ou $s = 2$.

On a alors:

$$-\frac{dn}{dt} = \frac{4RT}{3\eta N}[1 + A(\lambda/r)]n^2$$

$$\text{en posant} \quad \frac{4RT}{3\eta N} = K_0 = \text{constante}$$

$$\text{et } K = K_0[1 + A(\lambda/r)]$$

$$\text{on a } -\frac{dn}{dt} = Kn^2$$

* WHYTLAW-GRAY et PATTERSON, 1932a; SOULE et LE BOUFFANT, 1953; SMOLUCHOWSKY, 1918.

Si on suppose en première approximation que r n'est pas fonction de n on a immédiatement sachant que à l'instant initial t_0 la concentration est n_0

$$\frac{1}{n} - \frac{1}{n_0} = K(t - t_0)$$

B. Cas des aérosols hétérogènes en air calme

Pour la coagulation d'un nuage comprenant un large éventail de tailles particulaires, les calculs deviennent plus compliqués et le problème n'a pas reçu de solution générale.

MÜLLER (*Kolloid Z.*, 1926), donne une équation pour un aérosol ne contenant que deux tailles de particules, ce qui n'a aucune application pour un brouillard hétérogène.

$$-\frac{dn}{dt} = \frac{RT_S}{6\eta N} \cdot \frac{(r_1 + r_2)^2}{r_1 r_2} \left(1 + A \frac{\lambda}{r}\right) n^2$$

Quand $r_1 = r_2$ on retrouve la valeur correspondant à un aérosol homogène

$$\text{soit } \frac{(r_1 + r_2)^2}{r_1 r_2} = 4$$

$$\text{Quand } r_1 = 10r_2: \frac{(r_1 + r_2)^2}{r_1 r_2} = 12,1$$

soit une variation considérable du coefficient K de la formule de Smoluchowsky.

Remarques. Dans le cas particulier qui nous intéresse les particules solides ne sont isolées qu'au début de l'existence du nuage. La vitesse de chute, de deux particules de même rayon accolées, est supérieure à celle d'une particule unique de même taille, mais pour un aérosol primitivement homogène, l'effet de la sédimentation différentielle reste assez longtemps négligeable.

Dans ce cas la probabilité de rencontre ne dépend donc que du mouvement brownien et de la concentration :

$$-\frac{dn}{dt} = \frac{4RT}{3\eta N} \left(1 + A \frac{\lambda}{r}\right) n^2$$

λ est de l'ordre de 10^{-5} , et A a été calculé par Millikan :

V_1 étant la vitesse de chute d'une particule et V_s la vitesse calculée par la loi de Stokes on a $V_1 = V_s (1 + A(\lambda/r))$

"Millikan a calculé dans chaque cas $A(\lambda/r)$ d'où A et λ . Il a trouvé $A = 0,863 \dots$ " (Avy).

Pour les particules de diamètre supérieur à 1μ le facteur $A(\lambda/r)$ devient négligeable devant 1 et on peut écrire

$$-\frac{dn}{dt} = 2,97 \cdot 10^{-10} n^2$$

dans ce cas particulier la vitesse d'agglutination ne dépend que de la concentration du nuage, et est en particulier indépendante de la taille des particules.

Les calculs précédents ne tiennent pas compte de la notion d'efficacité des chocs et supposent que deux particules qui se rencontrent restent toujours liées.

2. Recherche d'un Mode Opératoire donnant une Bonne Précision

Nous nous proposons d'essayer de vérifier expérimentalement l'équation de Smoluchowsky.:

$$\frac{1}{n} - \frac{1}{n_0} = Kt$$

Les auteurs qui ont étudié l'agglutination spontanée se bornent généralement à exposer la théorie de Smoluchowsky en l'illustrant des chiffres trouvés par WHYTLAW-GRAY et PATTERSON en 1932. Ces derniers pour mesurer la concentration d'un nuage à un instant donné utilisaient l'appareil de Zsigmondy à cellule modifiée, deux glaces rodées limitant la profondeur du champ d'évolution des particules à 100μ ; un dispositif d'aspiration faisant circuler l'aérosol à étudier à travers la cellule, l'aspiration était interrompue à intervalles de temps réguliers pour permettre le comptage des particules situées dans le champ d'observation. La concentration était déterminée en faisant la moyenne des comptages effectuées sur un minimum de 60 champs comprenant chacun de 0 à 4 particules (cf. WHYTLAW-GRAY et PATTERSON, p. 24). Dans cette méthode, les résultats semblent être faussés, en particulier par le dépôt de particules sur les parois du circuit d'aspiration. Toutefois les auteurs ont bien vérifié la loi des inverses, ce qui peut s'expliquer en admettant qu'au cours d'une série de mesures conduites sur un même nuage avec les mêmes appareils de mesure, le pourcentage de particules non observées pour une raison ou pour une autre est constant. Ils trouvent pour K une valeur exagérée ($K = 5,3 \cdot 10^{-10}$ pour l'acide stéarique), ce qui s'explique car les concentrations sont mesurées toujours par défaut. D'autre part les auteurs précisent la concentration mais ne donnent aucune indication sur la granulométrie de leurs nuages, qui doit être très étalée. Nous avons vu plus haut que cela conduisait toujours à une constante d'agglutination plus élevée que la constante de Smoluchowsky, la sédimentation différentielle augmentant la probabilité de rencontre. Malgré cela ils ont trouvé pour K , et pour un corps donné, une valeur constante au cours de leurs différentes mesures. Ceci peut également s'expliquer, car les aérosols, produits dans les mêmes conditions et dans le même appareil, pouvaient avoir une granulométrie qui se trouvait reproduite au cours des essais successifs.

Il est intéressant de chercher à vérifier la théorie de Smoluchowsky en partant d'aérosols monodispersés.

A. Méthode adoptée

Les mesures de concentration sont difficiles et peu précises quand on étudie un aérosol d'acide stéarique, comme nous l'indiquons plus loin. Par suite, on a cherché à effectuer une seule mesure de concentration pendant toute la durée d'un essai grâce au procédé suivant. Multiplions les deux membres de l'équation de Smoluchowsky par n_0 , il vient:

$$\frac{n_0}{n_t} - \frac{n_0}{n_0} = K n_0 t$$

$$\text{soit en posant } \frac{n_0}{n_t} = U_t:$$

$$U_t - 1 = K n_0 t$$

U_t est mesurable avec précision car pour un prélèvement correspondant à un volume qu'il n'est pas utile de connaître, et c'est là l'intérêt de la méthode, U_t est égal au nombre total de sphères divisé par le nombre d'agglomérats contenant ces sphères (étant entendu qu'on compte également dans les agglomérats les sphères isolées qui au bout du temps t n'ont pas encore effectué de rencontre).

Si la loi des inverses est vérifiée la fonction $U = f(t)$ sera représentée par une droite de pente $P = K n_0$.

$K n_0$ se trouvant ainsi déterminé avec précision, une mesure de n_0 nous permettra de calculer K .

B. Mode opératoire

L'aérosol d'acide stéarique est injecté à la partie supérieure d'une chambre à poussières de 600 l ($1,20 \times 0,71 \times 0,71$ m). La cage est lavée pendant environ 90 min par l'aérosol injecté dans la cage à raison de 30 l par min, les orifices d'injection et de sortie de la chambre sont ensuite fermés, les perturbations se calment et la sédimentation commence.

La durée nécessaire à l'introduction du nuage dans la chambre explique que le nuage présente déjà un $(n_0/n) > 1$ à l'instant $t = 0$ correspondant à l'arrêt de l'injection et au début des mesures.

C. Mesure de U

Un certain volume du nuage est prélevé par sédimentation naturelle sur une lame de verre placée à la partie inférieure de la chambre pendant 10 min environ. Le dépôt recueilli sur la lame est examiné au microscope optique, et on détermine dans un certain champ les nombres $N_1, N_2, N_3 \dots N_n$ d'agglomérats de 1, 2, 3, ... n particules et on obtient:

$$U_t = \frac{N_1 + 2N_2 + 3N_3 \dots + nN_n}{N_1 + N_2 + N_3 \dots + N_n}$$

Le prélèvement se prolongeant de l'instant t_1 à l'instant t_2 , si la fonction $U = f(t)$ est linéaire, U_t mesuré correspondra à l'instant

$$t_t = \frac{t_1 + t_2}{2}$$

Les nuages sur lesquels nous avons expérimenté n'étant pas parfaitement homogènes et les grosses particules sédimentant plus vite que les petites, on assiste à un détitrage par sédimentation dans la partie supérieure du nuage, phénomène qui aurait tendance à exagérer la vitesse d'agglutination. Il convient donc d'éviter de prolonger les mesures de U au-delà du temps mis par les plus grosses particules pour parcourir la hauteur totale de la chambre à poussières, soit 120 cm.

D. Mesure de n_0

Les mesures par sédimentation directe donnent des résultats peu satisfaisants en raison des courants de convection pouvant exister au sein de l'aérosol. L'appareil de WHYTLAW-GRAY, CAWOOD et PATTERSON où deux plaques de verre peuvent coulisser et venir emprisonner dans le trou d'une plaque de cuivre une partie aliquote du nuage qui vient se déposer sur la plaque de verre inférieure, ne donne pas de résultats satisfaisants (voir (Avy) p. 109).

Nous avons pensé mesurer la concentration n_0 à l'aide du précipitateur électrostatique. Une longue lamelle de verre est introduite dans le corps de l'instrument, l'aérosol est aspiré à travers le précipitateur par un vase de Mariotte dont le débit est réglé de façon à recueillir toutes les particules contenues dans le volume aspiré sur une longueur d'environ 5 cm. Les particules sont ensuite dénombrées le long d'une génératrice $x'x$. On compte tous les 5 mm le nombre N de particules présentes dans un champ de $45 \times 108 \mu$, et on trace la courbe $N = f(x)$. Si on suppose que les particules se déposent régulièrement sur toutes les génératrices du corps cylindrique du précipitateur, la surface de la courbe $N = f(x)$ permettra de calculer n_0 ; nous avons montré expérimentalement que cette supposition n'est pas fondée, la lamelle de verre perturbant l'uniformité du champ électrique à l'intérieur du précipitateur.

Les concentrations très élevées que nous sommes obligés d'adopter, pour les raisons exposées dans la dernière partie de ce chapitre, interdisent l'emploi des appareils de prélèvement à membranes.

Finalement, l'appareil choisi est le précipitateur thermique, qui n'abîme pas trop les particules d'acide stéarique. On aspire à travers cet appareil un volume de l'ordre de 5 cm^3 seulement, les particules se déposent sur les deux lamelles circulaires. Les dépôts se présentent sous la forme de deux plages de 9,5 mm de long et de quelques centaines de microns de large; dans le sens de la longueur la concentration du dépôt est régulière, dans le sens de la largeur elle ne l'est pas.

3. Résultats expérimentaux

Les mesures ont été conduites sur des nuages de concentration étagées entre 44.000 et 495.000 particules par cm^3 ; en dehors de ces limites les mesures ne donnent plus aucune précision la coagulation étant trop lente ou trop rapide. Quand la coagulation est trop lente le nuage disparaît par sédimentation sur le fond de la chambre à poussières avant qu'une variation sensible de U soit décelée. Quand la coagulation est trop rapide on obtient de gros agrégats dont il est difficile de déterminer exactement le nombre de particules; d'autre part l'augmentation de probabilité de rencontre due à la sédimentation différentielle devient importante.

Pour mettre en évidence l'influence de la taille des particules nous avons opéré sur deux tailles très différentes soit 0,8 et 1,9–2,0 μ . Au-dessus de 2 μ les mesures ne sont plus possibles le nuage sédimentant trop rapidement.

Les résultats obtenus sont rassemblés dans le Tableau 3. Dans ce Tableau:

" a " désigne une valeur qui varie pour chacune des lignes du tableau.

" ΔU_0 " est égal à $(n_0/n)_{t_0} - 1$ qui est différent de 0 comme nous l'avons expliqué précédemment.

Ce tableau est illustré par les Figs. 15 et 16.

A. Vérification de la loi des inverses

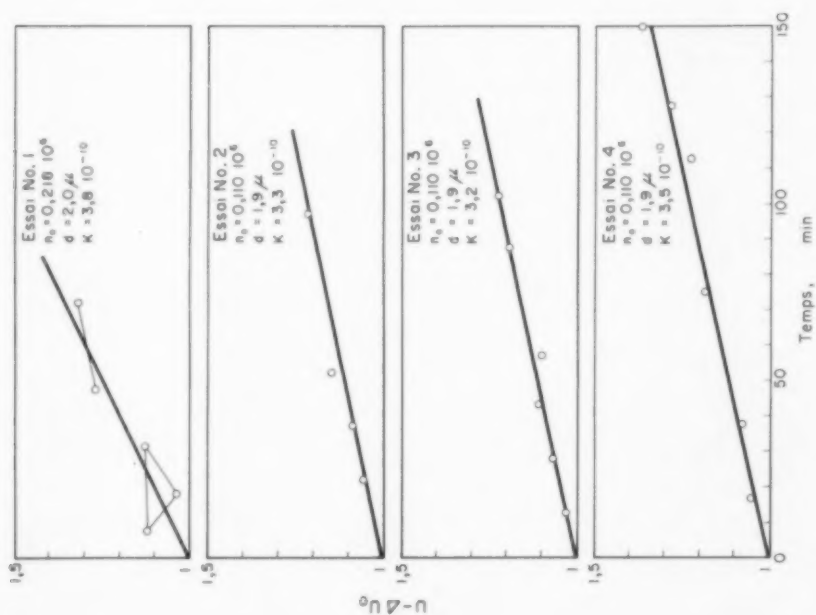
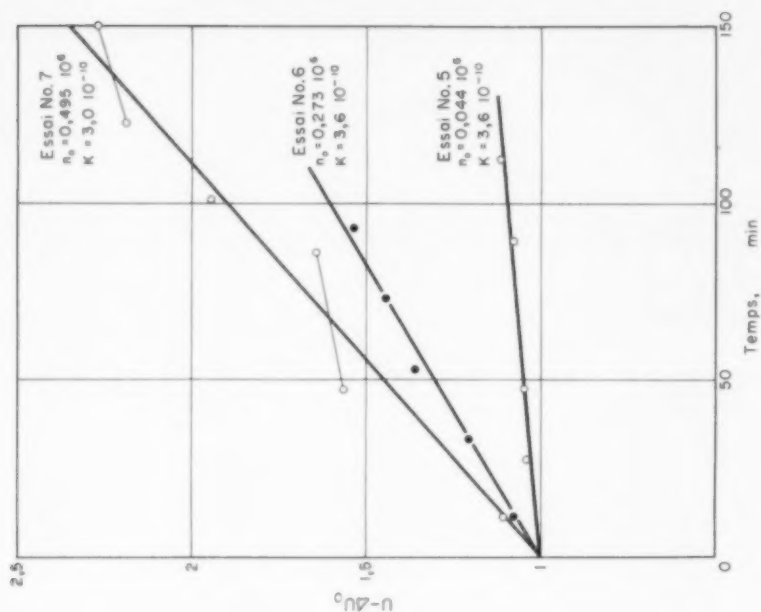
Les Figures 15 et 16 montrent que les fonctions $U = f(t)$ sont linéaires la pente p étant constante

$$\frac{dU}{dt} = P$$

ce qui entraîne

$$\frac{1}{n} - \frac{1}{n_0} = \frac{P}{n_0} t$$

La loi des inverses est donc vérifiée.


 FIG. 15. Courbes $U - \Delta U_0 = f(t)$.

 FIG. 16. Courbes $U - \Delta U_0 = f(t)$ —diamètre des particules $d = 0,8 \mu$

B. Vérification de la Théorie de Smoluchowsky

Si cette théorie est valable on doit avoir en tenant compte de la formule de Cunningham:

$$P/n_0 = K = K_0 [1 + A(\lambda/r)]$$

$$\text{Soit } P/n_0 = 2,97 [1 + A(\lambda/r)] \cdot 10^{-10}$$

$$\text{Nous poserons } P/n_0 = K \text{ mesuré} = K_m$$

$$\text{et } 2,97 [1 + A(\lambda/r)] 10^{-10} = K \text{ Smoluchowsky} = K_s$$

Les résultats obtenus pour K_m et K_s sont rassemblés dans le Tableau 4.

TABLEAU 3.

Essai N°	d_m (en μ)	t (en mn)	$a n_0$	$a n$	U	ΔU_0	$U - \Delta U_0$
1	2,0 μ	8	291	180	1,617	0,495	1,122
		18	158	103	1,534		1,039
		31,5	159	98	1,622		1,127
		47,5	233	132	1,765		1,270
		72	287	158	1,816		1,321
2	1,9	22,5	248	207	1,198	0,146	1,052
		37,5	249	202	1,233		1,087
		52,5	246	190	1,295		1,149
		97,5	314	231	1,359		1,213
3	1,9	12,5	313	370	1,159	0,130	1,029
		28	345	288	1,198		1,068
		43,5	236	191	1,236		1,106
		57,5	312	254	1,228		1,098
		87,5	275	208	1,322		1,192
		102,5	283	209	1,354		1,224
4	1,9	16,5	353	300	1,177	0,126	1,051
		37,5	370	307	1,205		1,079
		75	423	323	1,310		1,184
		112,5	431	318	1,355		1,229
		127,5	462	328	1,408		1,282
		149,5	484	325	1,489		1,363
5	0,8	27,5	251	211	1,190	0,151	1,039
		47,5	194	162	1,198		1,047
		89,5	226	184	1,230		1,079
		112,5	162	128	1,265		1,114
6	0,8	11,5	363	257	1,412	0,337	1,075
		33	350	227	1,542		1,205
		53	377	222	1,698		1,361
		73	351	197	1,782		1,445
		93	406	217	1,871		1,534
7	0,8	11,5	318	237	1,340	0,235	1,105
		47,5	212	118	1,797		1,562
		86	135	72	1,875		1,640
		101	161	74	2,176		1,941
		122,5	223	92	2,424		2,189
		150	228	91	2,505		2,270

TABLEAU 4.

Essai n°	d_m (en μ)	$(dU/dr) = P$	n_0 (en particules par cm^3)	K_m (K mesuré)	K_s (K Smoluchowsky)	$(K_m - K_s)/K_s \times 100$
1	2,0	$83,8 \cdot 10^{-6}$	218.000	$3,8 \cdot 10^{-10}$	$3,24 \cdot 10^{-10}$	+ 17,3 %
2	1,9	$36,3 \cdot 10^{-6}$	110.000	$3,3 \cdot 10^{-10}$	$3,25 \cdot 10^{-10}$	+ 1,6 %
3	1,9	$35,8 \cdot 10^{-6}$	110.000	$3,2 \cdot 10^{-10}$		- 1,6 %
4	1,9	$38,3 \cdot 10^{-6}$	110.000	$3,5 \cdot 10^{-10}$		+ 7,7 %
5	0,8	$15,85 \cdot 10^{-6}$	44.000	$3,6 \cdot 10^{-10}$	$3,64 \cdot 10^{-10}$	- 1,1 %
6	0,8	$99,0 \cdot 10^{-6}$	273.000	$3,6 \cdot 10^{-10}$		- 1,1 %
7	0,8	$150 \cdot 10^{-6}$	495.000	$3,0 \cdot 10^{-10}$		- 17,6 %

Remarques

(a) K_m est d'autant moins différent de K_s que la concentration est plus faible, ce qui est normal, les agrégats de quatre particules et plus étant très rares, l'augmentation de probabilité de rencontre due à la sédimentation différentielle reste faible. Au-dessus de $n_0 = 200.000$ la valeur de K_m est un peu forte (voir par exemple l'essai n° 1).

(b) Pour les fortes concentrations les mesures de U sont peu précises, les points expérimentaux sont beaucoup moins bien alignés et les droites plus difficiles à tracer (voir les essais n° 6 et 7). On note la présence de très nombreux agrégats réunissant plus de six, huit et même dix particules; quand les particules sont réunies en chaîne on les dénombre facilement, quand elles sont réunies "en amas" le décompte exact est impossible à effectuer; le nombre de particules contenues dans un agglomérat est alors déterminé par défaut. Cet effet, qui tend à abaisser la valeur de K_m , masque pour l'essai n° 7, où les gros agglomérats sont particulièrement nombreux, l'action de la sédimentation différentielle qui, elle, tend à augmenter K_m .

(c) Pour les essais n° 2, 3 et 4, effectués avec trois nuages identiques, n_0 a dû être mesuré après les essais sur un quatrième nuage identique aux trois premiers (le générateur fonctionnant avec les mêmes réglages), les prélèvements au précipitateur électrostatique en cours d'essai n'ayant pas donné satisfaction.

(d) Le mesure de n_0 au précipitateur thermique peut donner lieu à une légère erreur par défaut, les particules situées au centre du dépôt, donc les plus proches du fil chaud, peuvent fondre et on peut craindre la coalescence des particules fondues constituant une partie des agrégats. Toutefois, le prélèvement destiné à mesurer n_0 étant effectué tout au début de l'expérience, le nombre d'agrégats contenant plus de deux particules est très faible.

(e) Les particules étant solides, la formule valable quand r est fonction de n n'est pas applicable.

En résumé, quand les valeurs de n_0 sont bien choisies cette méthode fournit une vérification remarquable de la théorie de Smoluchowsky.

On peut donc dire que le diamètre de la sphère d'influence d'une particule est égal au diamètre de cette particule et que l'efficacité de choc est totale, c'est-à-dire que, dans le cas de l'acide stéarique que nous avons étudié, deux particules qui se rencontrent restent toujours liées.

La théorie de Smoluchowsky a pu être confirmée par l'expérience grâce aux aérosols monodispersés. L'utilisation des qualités particulièrement intéressantes de ces aérosols devrait faciliter grandement les études et les recherches concernant la mécanique des suspensions.

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THE PENETRATION OF FILTER PAPER BY COAL-DUST PARTICLES IN THE RESPIRABLE SIZE RANGE

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Abstract—The reduction in the amount of light transmitted through filter paper due to absorption by deposited dust particles is a simple method of measuring the concentration of an airborne dust cloud. The extent to which the penetration of the filter paper by the respirable size fraction will affect the validity of such measurements has been studied by measuring the penetration through two different types of filter paper. It is concluded that the amount of penetration found is too small to significantly lower the dust concentration as estimated by densitometric means.

INTRODUCTION

AIRBORNE dust can be measured by making use of its ability to absorb light. A simple method of using this principle is to draw a sample of dusty air through a filter paper by means of a small pump and measure the reduction in the amount of light transmitted through the paper due to some light being absorbed by the deposited dust particles (HODKINSON, 1961). But the smaller the particles are, the greater is the chance that they will completely penetrate the filter paper and thus fail to be measured. The experiments described in this paper were carried out to determine the extent to which respirable size particles of coal dust were able to penetrate two different types of filter paper at low air speeds. This was done by sampling an artificial dust-cloud of constant concentration with two adjacent membrane filters, one of which acted as a monitor, directly receiving the dusty air drawn through it, while the other had a piece of the filter-paper under test placed directly in front of it and therefore sampled only the dust that penetrated the filter paper. By comparing the concentration of any given size-range of particles on the two membrane filters, the extent to which particles in that size range had penetrated the filter paper could be determined.

EXPERIMENTAL

Silkstone coal dust, ground so that 85 per cent by weight passes through a 240 mesh B.S. sieve, was injected by means of a dust cloud former (HATTERSLEY, *et al.*, 1954) into a wind tunnel of 1 ft square cross-section in which the air velocity was 100 ft/min. The sampling instruments were placed 25 ft downstream from the dust injection point, where the airborne dust concentration had become uniform. The monitor membrane filter consisted of a $\frac{3}{8}$ in diameter circle of Sartorius A.F. 100 group filter (mean pore size $0.6-0.8 \mu$) held at the centre of the tunnel in a standard clip from the S.M.R.E. continuous sampler (WINDER, 1960). Air was drawn upwards through it by a small pump at a rate ($6.4 \text{ cm}^3/\text{min}$) that eliminated all particles greater than respirable size by a process of vertical elutriation (HAMILTON

and WALTON, 1952). A similar sampler was used for the filter paper under test (Whatman No. 1 or Wiggins Teape 6615), which was held in a clip below the one containing the membrane filter and joined to it by an airtight seal (Fig. 1). It was found by experience that a period of several hours sampling was needed for sufficient particles to penetrate the filter paper and produce a suitable counting density on the underlying membrane; the monitor sampler (which only required about 15 min

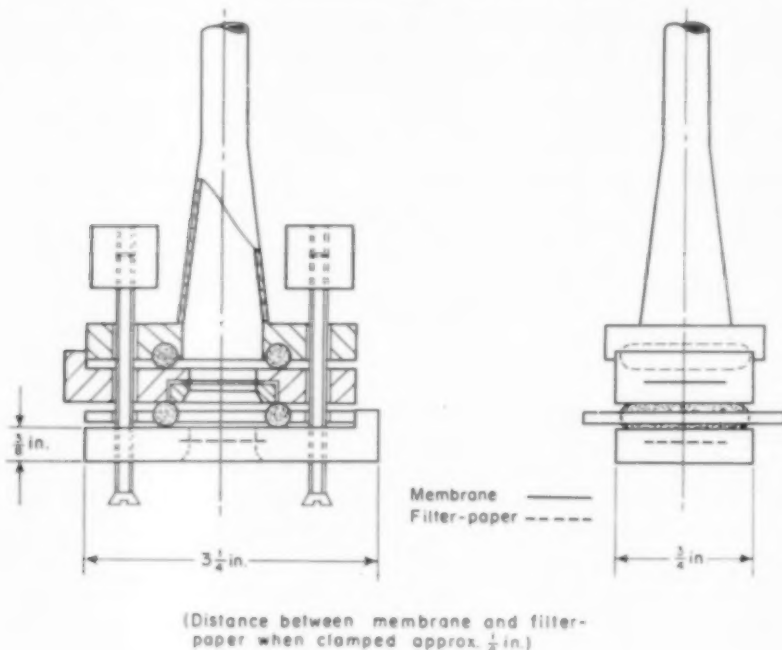


FIG. 1. Clamping arrangements for two sampling clips.

sampling time) was operated only in the middle of this longer period. The dust concentration was also measured during each test with a standard thermal precipitator (and also with a long running thermal precipitator which became available at the time when Wiggins Teape paper was tested) placed as close as possible to the sampling clips. The dust cloud was monitored at half-hourly intervals throughout all the tests by a P.R.U. Handpump (WATSON and HOUNAM, 1948) to check the constancy of the dust concentration.

EVALUATION OF SAMPLES

The stain densities of the filter paper samples were measured in the usual way (DAWES, 1954) and are quoted in terms of S value in Table 1.

The thermal precipitator samples were evaluated by the normal light field microscopy technique (DAWES and MAGUIRE, 1960) except that the Patterson-Cawood was replaced by a May graticule.

The membrane filter samples were also evaluated by light field microscopy after being mounted and at the same time rendered transparent in a solution of Canada Balsam in xylene (refractive index 1.522).

Both thermal precipitator and membrane filter samples were counted and sized, with the same optical settings of the microscope; for the former samples the usual system of counting several traverses across the dust trace was adopted whilst for the latter, forty separate graticule areas, located uniformly along two perpendicular diameters of the circular sample were counted. With the optical settings used, one graticule area corresponded to an area of 0.0025 mm^2 of filter, so that the total area counted was 0.1 mm^2 . Total counts were made in the $1-5 \mu$ range, and size distributions were determined over eleven ranges from 0.5 to 22.6μ .

RESULTS

Table 1 shows the concentrations in particles per cm^3 ($1-5 \mu$) of the experimental dust cloud as measured by the various monitoring instruments during four tests; the final column shows the concentration (again expressed as particles per cm^3 ($1-5 \mu$)) of the cloud penetrating the corresponding filter paper. The close agreement between the various monitoring instruments can be seen. The size distributions of all these samples were determined and the results of two experiments, namely Nos. 1 and 3 (Table 1), expressed in terms of number of particles per cm^3 air, μ size range are plotted in Fig. 2. By comparing the figures for the membrane filter behind the filter paper with the monitor membrane filter the percentage penetration in each size range can be obtained. The mean penetration results obtained from the two tests carried out with each type of filter paper are

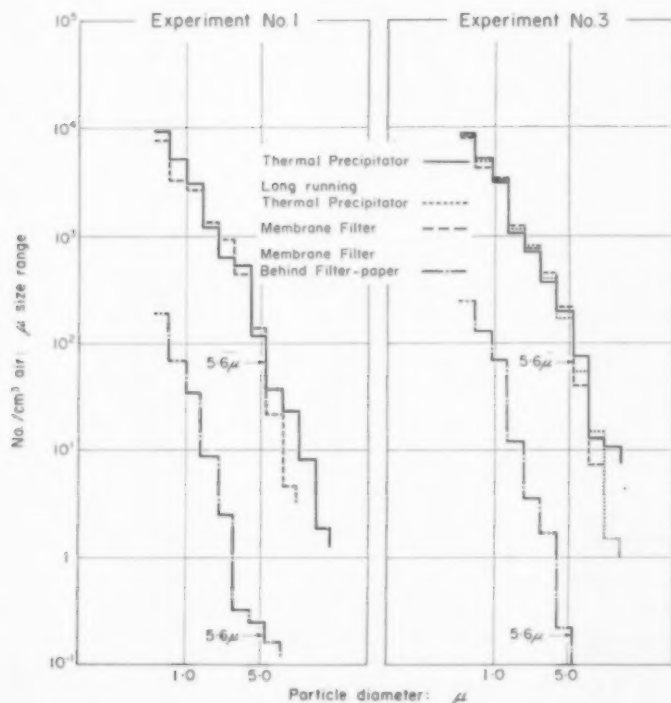


FIG. 2. Size distributions obtained with different monitoring instrument



FIG. 3.

TABLE I.

Experi- ment Number	Type of Filter paper	S value	L.R.T.P. p.p. cm ³ ($>1\ \mu$)	Standard T.P. (p.p. cm ³ 1-5 μ)	Membrane Filter (Monitor) (p.p. cm ³ 1-5 μ)	Membrane Filter (Behind Filter) (p.p. cm ³ 1-5 μ)
1	Whatman No. 1	3.65	—	5592	5524	47
2	Whatman No. 1	3.92	—	5466	5301	61
3	Wiggins Teape No. 6615	17.32	5955	5612	6117	90
4	Wiggins Teape No. 6615	15.02	5730	5713	5997	94

plotted in Fig. 3. They show that there is virtually no penetration of either type of filter paper by coal-dust particles greater than $5\ \mu$ in diameter. Penetration occurs below this size, being about 1 per cent in the $1.4\text{--}2.0\ \mu$ size range and

rising to about 3.5 per cent in the 0.5 to 0.7 μ size range, which was the smallest range counted.

CONCLUSIONS

The results of the experiments described show that, at the low air flow rates used, coal dust particles greater than 5 μ in diameter do not penetrate either of the two types of filter paper tested. Below this size there is some penetration, but its amount is too small to significantly lower the dust concentration estimated by densitometric means.

Acknowledgement—The illustrations in this paper are Crown Copyright.

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THE FILTERING EFFICIENCY OF SELECTED PAPERS

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INTRODUCTION

THE FIRST instrument used for sampling airborne particulate contamination at the Atomic Energy Research Establishment, Harwell was the type 1042 dust sampling unit, later superseded by the not dissimilar type 1355 dust sampler (1958). Both these instruments used a fan to aspirate the air through a small area of filter paper on which the dust was retained. Fans only provide a limited amount of suction and a selection of filter papers was tested in order to ascertain the most suitable for use with these instruments. The results were given in a report by HOUNAM and BUSBRIDGE (1949) which had a restricted circulation but it has been suggested that they may be of general interest and so merit publication.

DESCRIPTIONS OF TESTS

The following properties of the papers were measured.

- (a) Thickness (T): some 50 sheets were held under light compression between two flat, parallel surfaces and the distance between the surfaces was measured.
- (b) Weight per unit area (W): a known area of paper was weighed, no special precautions being taken to maintain a constant humidity. The results for cellulose papers may therefore be as much as 15 per cent greater than the dry weights.
- (c) Resistance to air flow (R): The pressure drop across a disk of paper clamped in a holder to present an exposed area 4.5 cm diameter at an air flow of 30 l./min. The face velocity is 31 cm/sec.
- (d) The percentage penetration through the paper of the aerosol used for the standard Methylene Blue Particulate Test (1955). The percentage efficiency of a filter is 100 minus this quantity. The penetration was measured at the same flow rate as that at which the resistance was determined.

The results of these and a few more recent tests are given in Table 1. The Methylene Blue Particulate Test is stringent because the sizes of the particles are such that many are near the optimum size for penetration through a filter.

According to GREEN and LANE (1957) 90 per cent by number of the particles of the test cloud are 0.2μ in diameter or less, 48 per cent are 0.05μ in diameter or less and the mass median diameter is about 0.5μ .

When a small area of paper is used for the test there is a tendency for the test cloud to choke the surface of the paper and improve its efficiency as a filter. The time of test was therefore kept to the minimum consistent with accuracy.

Efficient papers with a percentage penetration between 0.02 per cent and 0.2 per cent required a test lasting 2 min. When the penetration was in the range of 0.2 per cent to 2 per cent a 12 sec test sufficed. Percentage penetrations as high as

8 per cent could be measured if the time of test was reduced to 3 sec. As it is difficult to carry out tests of shorter duration with precision, papers with a very high penetration have been assessed by direct comparison of the filtered and unfiltered test cloud in tests of less than ten seconds duration.

When a homogeneous aerosol is passed through a sheet of clean filter paper the ratio of the effluent to the incident concentrations (C and C_0) is independent of the magnitude of the concentration within wide limits, and for a number n of sheets in series.

$$C = C_0 e^{-\alpha n}$$

where α is a constant for a given type of paper.

Since C/C_0 is the fractional penetration then if P is the logarithm to the base 10 of 100 divided by the penetration percentage we have

$$P = \log_{10} (C_0/C) = 0.4343 \alpha n$$

The resistance R of a number of sheets in series varies directly as the number of sheets hence

$$P = kR$$

It is not to be expected that the constant k will have the same value for sheets of different papers each about the same thickness but of different resistance. Nor would it be expected to hold for the inhomogeneous Methylene Blue Test Cloud. The ratio P/R does however provide a convenient index of the relative merits of different papers on the criterion of efficiency, on the methylene blue assessment, for a given resistance. For comparison with the values of R the values of P for the papers tested are also listed in Table I.

TABLE I. PERFORMANCE OF FILTER PAPERS

Sample No.	Filter Paper	T (cm)	W (g/cm ²)	R (in. W.G.)	Penetration (%)	P
1	Whatman No. 1	0.019	0.009	29	2.0	1.70
2	" No. 2	0.018	0.013	54	0.4	2.40
3	" No. 3	0.041	0.019	43	0.2	2.70
4	" No. 4	0.023	0.010	7.2	12	0.92
5	" No. 30	0.023	0.009	17	4	1.40
6	" No. 31	0.030	0.010	10	8	1.10
7	" No. 40	0.023	0.009	78	0.02	3.70
8	" No. 41	0.023	0.010	6.4	36	0.44
9	" No. 52	0.018	0.010	45	0.8	2.10
10	" No. 541	0.019	0.009	4.4	64	0.19
11	" Soxhlet	0.114	0.036	4.8	25	0.60
12	" AGF/A	0.045	0.005	6.0	0.04	3.40
13	D. H. Separa	0.016	0.009	2.3	40	0.40
14	Typical Blotting	0.020	0.009	11	12	0.92
15	Fourstones Sample A	0.035	0.013	3.0	20	0.70
16	Wiggins Teape 6615	0.050	0.009	3.0	20	0.70
17	"G" Type Esparto	0.32	0.073	8.4	9	1.05
18	Pyrene respirator pad	0.24	0.031	2.2	17	0.77
19	Cellulose-asbestos					
	American origin	0.114	0.020	11.2	0.08	3.10
20	Cellulose-asbestos					
	British origin	0.038	0.009	14.4	0.06	3.22
21	Cellulose-asbestos					
	from Chema filtration unit	0.032	0.013	15.6	0.6	2.22

DISCUSSION OF RESULTS

The results for P and R in Table 1 have been plotted in Fig. 1. It will be noted that for the cellulose papers the points lie about a curve suggested by the dotted line and not about a straight line that would show a linear relation between P and R . The methylene blue particulate test cloud is inhomogeneous and the most easily filtered particles are removed preferentially by the less efficient filters.

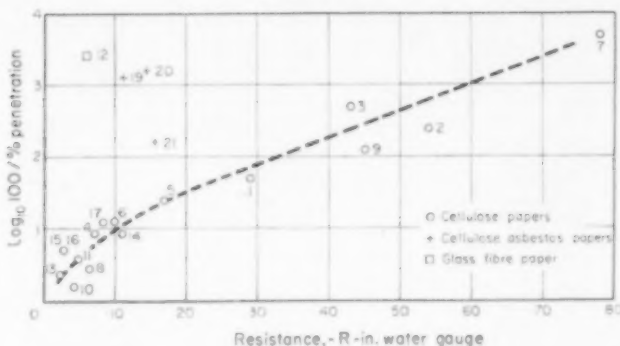


FIG. 1. Performance of selected filter papers.

Since the assessment is essentially on a weight basis filters which appear to be relatively more efficient may not be good for fine particles. This is the reason why cellulose papers of low resistance tend to have the highest values of P/R . It will also be apparent from Fig. 1 that samples 8, 10 and 13 have inferior performances compared with samples 15 and 16. The ratio W/T for the latter is lower than for samples 8, 10 and 13. It is generally found that of two papers with the same resistance the paper of more open texture, and hence having a low ratio of W/T , is a more efficient filter than the more highly compressed one.

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NEWS

Annual American Industrial Hygiene Association Meeting Honours Dr. Ethel Browning, M.D.

(see frontispiece)

THE AIHA held its annual national technical meeting during the week of 9 April, 1961 in Detroit, Michigan, with the American Conference of Governmental Industrial Hygienists. Despite it being the first time these groups met apart from the Industrial Medical Association, the American Association of Industrial Nurses and Industrial Dentists, which were meeting concurrently on the West Coast, the attendance exceeded all past years. There were 736 registrations, and 50 wives from a total membership of 1200 of the AIHA and 500 of the ACGIH. There were 100 exhibitors. Ninety-four technical papers were presented in the sessions of the AIHA in the fields of engineering, analytical chemistry, toxicology, noise, radiation and general industrial hygiene. In addition, approximately a dozen 30-minute papers on the ACGIH program dealing with governmental occupational health programs were presented.

The highlight of the meeting was the AIHA Annual Banquet, at which DR. ETHEL BROWNING was honoured with honorary life membership in the association. Dr. Browning is the first doctor outside the United States, and the first Briton to receive this tribute. Also receiving honorary membership were DR. FRANK A. PATTY, formerly Medical Director of General Motors Corporation, DR. WILLIAM F. VON OETTINGEN, and DR. CLARENCE D. SELBY. It was recognition of professionals by professionals. In announcing her honour, President Jack A. Radcliffe, Chief Industrial Hygienist for Ford Motor Company referred to Dr. Browning's professional literary attainments, one of which, *Toxicology of Industrial Organic Solvents* is now a desk reference of industrial hygienists and toxicologists in America. In accepting the honour, Dr. Browning brought personal greetings from Dr. Scott, President of the British Association of Industrial Medical Officers and briefly compared the factory inspection system of England with the industrial hygiene procedures in the United States, interspersing amusing personal vignettes that endeared her to the audience. Dr. Browning outlined the objects and the work of the British Occupational Hygiene Society and the Ergonomics Research Society. At the conclusion of her remarks Dr. Browning was given a standing ovation.

Three other awards were conferred: MANFRED BOWDITCH, long known in industrial hygiene circles in the U.S.A., was given posthumously the Cummings Memorial Award. DR. WILLIAM G. FREDERICK, Director, Bureau of Industrial Hygiene, Detroit Department of Health, presented the Cummings Memorial Lecture. To DR. HARVEY B. ELKINS, Director, Division of Occupational Hygiene, Massachusetts Department of Labor, Award of Merit in recognition of the outstanding man of the year in industrial health. To MR. HOWARD B. KUSNETZ, DR. BERNARD E. SALTZMAN and MARSHALL LANIER, of the Division of Occupational Health of the U.S. Public Health Service, for the best paper of the year published in the official journal of the AIHA.

A novel feature of the meeting was the introduction of the nine "refresher" courses lasting for one morning, given on dust-counting and sampling, noise, heat, and radiation measurement, and on toxicology. Those in attendance declared the venture highly successful.

Growing success was apparent also among the eight working committees of AIHA, task force groups in air pollution, analytical chemistry, engineering, and hygienic guides, noise, radiation, respiratory protective equipment and toxicology. These committees develop manuals, codes, or other types of practical publications, in the field of environmental health that are widely subscribed and help sustain the parent organization. The ACGIH has similar functional committees.

The 1961 meeting was uniformly declared the largest and most successful in the 22 years of annual meetings of the AIHA.

Newly elected officers of AIHA are, President, WILLIS G. HAZARD, Owens-Illinois Glass Company; President-elect, KENNETH MORSE, U.S. Steel Corporation; and Treasurer, HERBERT E. STOKINGER, Division of Occupational Health, U.S. Public Health Service.

Small Factories and their Health Services

Eighty to ninety per cent of factories in most European countries employ less than 100 workers. Because these factories are so small they have as a rule no industrial health services; hence, supervision of working conditions and sanitation is poor and there is no medical and nursing care. The accident rate in small factories is more than twice that of the larger ones, where proper health services are available.

Of the 220,000 factories in Britain, 150,000 employ 10 or fewer workers. More than a million people there work in factories employing 25 or less, the number of such factories having nearly doubled in the last 25 years. In Italy, 95 per cent of industrial plants have less than 100 workers, in Switzerland 90 per cent, in Belgium 96 per cent, in Denmark 99 per cent and in Sweden 92 per cent. In the Netherlands, about 50 per cent of the workers have no access to industrial medical care.

The provision of health services for small industrial concerns is thus a matter of great importance, and a number of different ways of organizing such services have been developed in various parts of Europe.

These were studied at a conference in Dublin called jointly by the Regional Office for Europe of the World Health Organization (WHO), and the International Labour Organization. About 40 experts, including representatives of employers' and workers' organizations from 22 countries participated in the meeting, which lasted from 8 to 16 May at Dun Laoghaire (Dublin).

BOOK REVIEWS

Toxicity of industrial metals, ETHEL BROWNING. Published by Butterworth & Co., London, pp. vii+325, index pp. 14. 50/-.

THE degree of toxicity of a metal and its compounds is not easily predicted. The physical form, the valency, the organic or inorganic nature, the route of entry to the body, and the particle size if inhaled, are known to be of great significance in determining a metal's capacity to affect health. Much has been learned in recent years, both of the older metals like lead, mercury and tin, and also of those such as beryllium, selenium and vanadium, which have lately attracted attention because of their special properties. It is becoming increasingly evident that many metals, in trace quantities can exert a profound influence on cell metabolism, either as activators or inhibitors of special enzyme reactions, or by becoming actual components of metallo-enzymes. Frequently, of course, this enzymatic activity is beneficial, but it is not always so; for example it has been shown that beryllium may be an inhibitor of the alkaline phosphatase enzymes, possibly by this means exerting some of its toxic effects.

Experimental work in this field is enlarging, and much of the published observations concerning it may well escape notice in the absence of a careful search through a variety of specialized journals such as those treating of botany, physiology, biochemistry, toxicology, pharmacology, veterinary science and experimental medicine. There are many who will therefore be grateful to Dr. Ethel Browning for providing, in a book of convenient size, so much information on this subject. Even general physicians and biochemists, who are not closely concerned with the mining, smelting and refining of metals, or with the health of those employed in these occupations, are likely to find here plenty of interest to them. To those physicians and other hygienists who work in chemical, metallurgical and mining industries, this book will certainly be welcomed, not only for the facts and theories gathered from so many diverse sources, but for the excellent lists of references to work published in several countries.

The author has met with a full measure of success in her intention to review in their main features, the occurrence, preparation, physical and chemical properties, metabolism and toxicology of the principal metals encountered in industry. Particular attention has been given to their absorption, excretion and distribution within the body as a guide to their site of action and to the possible prevention of toxic effects.

In deciding what element may properly be called a metal, Dr. Browning has in part been guided by the Oxford New English Dictionary. This has led to the inclusion of rhenium and rhodium, at present of small significance, and to the exclusion of phosphorus, which has highly toxic properties and is of great importance in industry. To some it will probably be a mild disappointment that it was thought necessary to draw a line at this particular point, and perhaps it may be possible for some discussion of both phosphorus and uranium to appear in later editions of this very useful book.

T. G. FAULKNER HUDSON

British Medical Bulletin, Hypothermia and the effects of cold. Published: Medical Department, The British Council, 65 Davies Street, London, W.1. Editor A. S. PARKES: Vol. 17, No. 1: Price £1 0s. 0d.

THIS bulletin presents a full review of the considerable amount of information which has been accumulated over the past fifteen years on the effects, in animals and man, of exposure to extreme cold. There are fourteen separate papers covering various aspects of the subject, ranging from the effects on poikilothermic and hibernating animals, through the effects on man, to the effects on particular regions and organs in the human body. The emphasis throughout is upon conditions in which a part or the whole of the organism is cooled to a temperature substantially below that normally maintained.

In the introductory paper Dr. EDHOLM emphasizes that under the normal circumstances of life man is singularly successful in preventing gross changes from occurring in the general body temperature, by use of suitable clothing assemblies and protective buildings. There is thus little in the bulletin which is of direct application to the problems of the thermal environment in work places. The majority of the work reviewed has been performed in connection with problems of survival at sea and in the use of hypothermia in medicine and surgery.

In a paper on local cooling in man Dr. Fox refers to experiments in which the hands and forearms were exposed to severe cold. These demonstrated that manual dexterity is severely impaired before any change in the strength of grip is apparent. No clear evidence of any acclimatization to such local effects has been adduced. Only in people habitually living in a cold climate has any evidence of improved performance been found, and this is thought to be a general adaptive change rather than a specific result of the local stimulus.

The effects of local cooling on the component systems involved—the vascular, muscular and nervous systems of the hands and arms—are also considered.

Dr. HART reviews the physiological effects of continued exposure to cold of animals and men. Man reacts less markedly than many animals. There appear to be two types of adjustment made in man; a tendency for the blood flow to the extremities to increase, thus enhancing the heat flow, and also an increase in the tolerance to cooling in the peripheral tissues. The extent of these adjustments appears to vary between races.

Dr. DEPOCAS refers to the biochemical changes which have been observed in animals exposed to cold. There is a gradual reduction in the extent of shivering as other methods of generating heat are brought into play.

The remaining papers consider the effects of hypothermia induced in the laboratory and hospital and are outside the scope of those concerned with the effects of exposure to cold conditions in the working environment.

D. TURNER

Radiation protection and recovery. Published by the Pergamon Press: Edited by ALEXANDER HOLLAENDER, London and New York, 1960: Pages pp. v.+392: Index 379-392; Price 70/- 1st Edition.

THIS book is a distinguished contribution to radiobiological literature, mainly from the Oak Ridge School of Radiobiology. It must be stressed, however, that the term "radiation protection" referred to in the title does not mean practical

protection from radiation in industry or in the laboratory. The type of protection described is that produced by chemical and physical agents acting on living cells. There are many substances, of which one of the better known is cysteamine, which may partially protect animals from the effects of radiation if administered before the radiation is given. It is impracticable to apply such experiments to man since the toxic dose is much too near the protective dose. Nevertheless these substances are extremely useful tools in helping to elucidate the fundamental mode of action of ionizing radiations on the tissues. The volume under review is therefore a series of essays on radiobiology revolving around this theme. There is a particularly interesting chapter on chemical and physical methods which modify even the genetic response to radiation; again these methods are as yet of no practical value in human protection.

A technique which has been of much recent interest in assisting recovery from acute radiation injury is the donation of bone marrow from an unaffected individual. L. H. SMITH and C. C. CONGDON give a valuable review of this method of therapy, particularly stressing the experimental support for these ideas and not omitting reference to the immunological dangers of "secondary disease".

I. S. EVE

The relation between pneumoconiosis and environmental conditions: An analysis of the results of the first series of X-ray surveys in the National Coal Board's Pneumoconiosis Field Research. D. HICKS, J. W. J. FAY, J. R. ASHFORD and S. RAE. Printed and published by the N.C.B., Hobart House, London, S.W.1. March, 1961.

THE National Coal Board's Pneumoconiosis Field Research which is being carried out at the invitation of the National Joint Pneumoconiosis Committee of the Ministry of Power aims to determine—

"how much and what kinds of dust cause pneumoconiosis and to establish what environmental conditions should be maintained if mineworkers are not to be disabled by the dust that they breathe during the course of their work."

The research is being conducted at 26 collieries which have a wide geographical distribution over the British coalfields and which have been chosen to cover the range of environmental conditions in British coal mines thought to be relevant to the causation of pneumoconiosis.

Earlier studies of the prevalence of pneumoconiosis had suggested that both the concentration and composition of the airborne dust might be contributory factors. It was decided that the selection of collieries in the present research programme should be made on the basis of a general assessment of environmental conditions in terms of a factorial design with four factors each at two levels, high and low. The four factors chosen were:

- i the rank of coal in the seams worked;
- ii the dust concentration at the coalface on the coal getting shift;
- iii the average ash content of the coal seams excluding the free dirt, and
- iv the quartz content of the roof and floor strata.

It was envisaged that because the attack and progression rates of pneumoconiosis are comparatively slow it was likely to be 10 to 15 years before reliable

conclusions could be reached. In the meantime, however, a great deal of information would be collected in the normal course of the investigation.

The present report is therefore only a progress one and is based on the first series of medical surveys at the 26 collieries carried out during the period 1953 to 1958. These have revealed the prevalence of radiological pneumoconiosis in its various categories amongst the men examined. In addition a record has been obtained of each man's industrial history.

Data have been accumulated for upwards of 30,000 mineworkers in terms of their X-ray categories at the time of the first medical surveys and their past industrial histories to that date, which provide a potential source of much useful information about the relation between pneumoconiosis and past environmental exposure. Because of the lack of detailed knowledge about past dust levels prior to the field research programme any conclusions at this stage cannot be of a quantitative nature, in the sense of relating actual dust exposure to the incidence of pneumoconiosis.

The report describes the planning of the investigation and the selection of the pits concerned, together with a general account of the prevalence of simple pneumoconiosis and progressive massive fibrosis. The mathematical treatment of the data, including the methods of multi-dimensional analysis, is explained in detail.

While certain attempts are made to relate the prevalence of pneumoconiosis revealed—the first medical surveys at the selected pits with the past occupational histories of the men examined, the ultimate objectives of the research will not be achieved for many years, and probably not with precision until the third or possibly the fourth medical surveys have been completed. The limited studies now reported however, will be of the greatest interest to those concerned with the problem of pneumoconiosis in the mining industry. The National Coal Board research scheme is the largest and most comprehensive project in this field attempted in the world to date.

C. G. WARNER

Symposium on dust control in the pottery industry, 8th April, 1960. The British Ceramic Research Association, Special Publication No. 27, 1961, pp. 95.

THE symposium reviews some of the progress made in recent years into the problems connected with the health hazard due to dust in the pottery industry.

Dealing with the incidence of pneumoconiosis and tuberculosis in the industry, Dr. E. POSNER presents a critical analysis of the numbers of cases of pneumoconiosis certified in the 9 years 1950 to 1958, when 2,421 new cases from the industry were diagnosed by the Pneumoconiosis Medical Panels. It is reasonably certain that the annual figures contributing to this total do not truly express a rising or falling incidence of the disease. The higher levels of certification between 1953 and 1956 were almost certainly due to the first mass radiography surveys in the pottery industry, when the majority of workers were X-rayed for the first time during their working life. The figures prove only the well-known experience that the annual number of newly found cases of pneumoconiosis depends to a large extent on the radiological coverage of the population under risk.

Regarding a standard of air-borne dustiness in potters' shops Mr. V. B. JONES said that the concentration should be well below 100 p.p. cm³, while the figure

to aim at should be 40 p.p. cm³. These values refer to particles in the size range 0.5-5 μ as determined from thermal precipitator sampling.

Forty p.p. cm³ is not an unreasonable target as it can be achieved under conditions of good ventilation and good housekeeping; it will give a high degree of safety and is quite practicable.

Industrial points of view were presented by Mr. J. M. PALMER, who described design principles as applied to ventilated hoods and booths, and by Dr. C. J. STAIRMAND, who discussed the problems of dust arrestment and disposal after it has been extracted from the work rooms via properly designed hoods, etc. This paper contained valuable data comparing the working efficiencies and costings of various de-dusting systems including cyclones, precipitators, fabric filters and scrubbers.

Contributions by Mr. W. A. BLOOR dealt with methods of assessing dust conditions and a consideration of the properties of types of fabric used for protective clothing. Heavy cotton drill commonly used for overalls and aprons has a high capacity for picking up dust, which can be easily dislodged by gentle movements and so constitute a serious source of secondary air-borne dust. Terylene has been shown to be the best alternative material, as it is relatively impervious and is also durable and easily laundered.

In summing up the deliberations of the meeting it was agreed that while the main task of medicine is in the preventive field and that study of the clinical and occupational histories of cases can pinpoint black spots in the industry, the practical remedies lie in the hands of management, engineers and scientists. In view of developments on these lines in recent years it is felt that the future of pneumoconiosis certification rates in the pottery industry can be viewed with a careful optimism.

C. G. WARNER